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TWO TRANSMITTING VALVES FOR USE IN MOBILE INSTALLATIONS

by E. G. DORGELO and P. ZIJLSTRA. 621.385.4:621.396.61:621.396.72

When in 1896 Marconi succeeded in developing wireless telegraphy into a technically useful means of communication the main application envisaged was for establishing communication between ships at sea and the shore. In those days there was little difference between a fixed radio station and a mobile one, but this changed when, some time later, wireless came to be applied also to aircraft and equipment began to appear in special forms most suited for their purpose. It was about that time, too, that telegraphy was largely ousted by telephony. It is only in recent years that radiotelephony has come to be used on a large scale in automobiles and trains, for which purpose special frequency bands were allotted by the last radio conference at Atlantic City.

As regards the transmitting valves developed for this new form of mobile installations, they are required to possess great mechanical strength combined with high efficiency, the latter property being demanded on account of the fact that the most efficient use possible has to be made of the power available, since this is supplied by a source of only limited capacity, in a car, for instance, by the battery.

In recent years small, mobile, radio-telephonic transmitting and receiving installations have become very popular as a means of meeting a need felt in many directions. When automobiles, trains or small vessels are equipped with these sets communication can be maintained between them and with one or more fixed stations. As examples may be mentioned: taxi companies, fire brigades, police forces, military columns, harbour works, railways (both for the convenience of passengers and for use in marshalling yards), outposts or remote plantations in inhospitable regions, doctors and business people desiring to keep in touch with their homes, offices or works, etc., etc.

For such purposes as these the transmitter and the receiver are usually built together, sometimes making such a compact whole that it can be carried on the back or even in the hand (we have in mind the "walkie-talkies" and the "handie-talkies" which rendered such good services in the allied armies during the war).

This article deals with two transmitting valves that have been developed specially for such mobile installations. The need for new valves arises mainly from the fact that the supply source — the accumulator battery of a car or the dry batteries of the smaller, portable sets — is of a very much more limited capacity than in the larger mobile installations. It is therefore necessary that the transmitting valves should work with a high efficiency and possess such properties that a small number of stages suffices (for amplification and frequency multiplication). Furthermore, valves destined for use in trains or automobiles have to withstand greater mechanical shocks than occur on board ships.

Before proceeding to describe these new valves it is deemed necessary to consider briefly some points that are of importance for mobile transmitters.

Mobile transmitters

Wavelengths

Mobile radio stations were officially recognised at the international telecommunication conference held at Atlantic City in 1947, when a number of frequency bands were allotted to these stations.

For such of these bands as lie between 54 and 420 Mc/s (5.55 to 0.714 m waves) their distribution is indicated in *fig. 1*.

The other bands outside these limits have not been included in this diagram for the following reasons. At frequencies below a certain limit there is a risk of the waves being reflected by the ionosphere and reaching the earth again in parts far removed from the transmitter [1]); welcome use is made of this for long-distance radio communication, but for transmitters intended only for short-range work, like mobile transmitters, this reflection by the ionosphere is undesirable because it is apt to lead to interference over wide ranges where the same wavelengths are being used. At frequencies of 54 Mc/s and higher there is no need to take account of this effect, although at the highest allotted frequencies under certain atmospheric conditions an inversion of the temperature gradient occurs and the signals may cover a range of some hundreds of kilometres, but then the ionosphere has nothing to do with this; such conditions, however, very seldom occur.

The other limit, 420 Mc/s, is about the highest frequency at which the transmitting valves to be described here still work with a satisfactory efficiency; for still higher frequencies entirely different types of valves would be required.

For the allocation of frequencies for working mobile transmitters the world has been divided into three zones, where the following arrangements apply for the frequencies between 54 and 420 Mc/s.

In *zone I*, covering Europe, Africa and some parts of Asia, the frequency bands that may be used are: 70-72.8, 75.2-78, 80-83, 85-87.5, 100-108, 156-174, 235-328.6 and 335.4-420 Mc/s. There are some exceptions however: the 85-87.5 Mc/s band does not apply for Great Britain, which has instead the disposal of the 66.5-68 Mc/s band; South Africa and its mandatory territories have been allotted, instead of the 100-108 Mc/s band, the bands 133-144 and 146-174 Mc/s and also, but only for mobile stations used for broadcasting, the 54-68 Mc/s band.

Zone II, comprising mainly North and South America, has been allotted the 54-88, 132-144, 148-220, 225-328.6 and 335.4-420 Mc/s bands.

Zone III, consisting mainly of that part of Asia not included in zone I and of Australia and New Zealand, has the disposal of the bands 54-68, 70-78, 80-87 (in Australia and New Zealand 80-85), 132-144 (not in Australia and New Zealand), 148-200 (in Australia limited to 156-170 and 178-200, in New Zealand limited to 156-200), 235-328.6 and 335.4-420 Mc/s.

In order to avoid interference with or from other radio communications, mobile transmitters are not allowed to work outside the fixed frequency bands, and in order to avoid any mutual interference their frequency has to be highly constant. For this reason **crystal control** has to be applied.

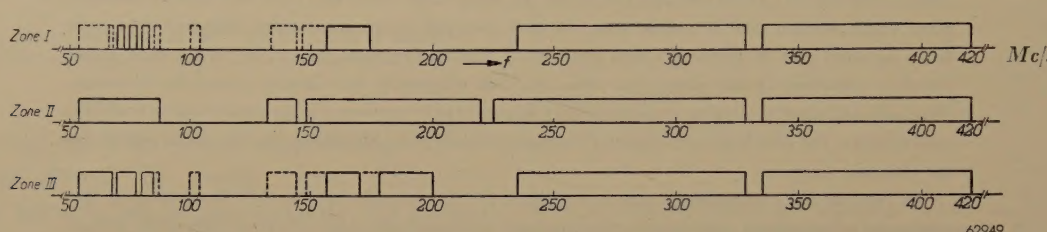

Fig. 1. The frequency bands allotted to mobile transmitters by the International Telecommunications Conference held at Atlantic City in 1947, for so far as these bands lie between 54 and 420 Mc/s. Roughly speaking zone I comprises Europe, Africa and part of Asia, zone II North and South America, and zone III the part of Asia not belonging to zone I, and Australia and New Zealand. The bands denoted by dotted lines can only be used in certain parts of the respective zone. For further details see the text in small type.

Power and range

The power of mobile transmitters is closely related on the one hand to the minimum range required and on the other hand to the permissible weight and volume of the apparatus, including the power supply unit.

The range depends not only upon the power radiated by the aerial but also to a large extent upon the construction and height of the aerial, whilst also the surroundings are of great influence. The aerial constructions most favourable for radiation are generally too cumbersome to be of use on an automobile or train. The higher the aerial the greater is the range, but then of course the height is limited for travelling vehicles; on an automobile, for instance, as a rule a simple vertical rod on the roof is used. In open spaces the range is much

[1]) See, e.g.: C. J. Bakker, Radio investigation of the ionosphere, Philips Techn. Rev. 8, 111-120, 1946.

greater than in built-up areas; the adverse influence of buildings is, roughly speaking, felt most at the highest frequencies, though there are exceptions to this rule. In New York, for instance, it has been found that in narrow streets shorter waves are more readily reflected downward by buildings than are longer ones. A second reason for shorter waves being sometimes more satisfactory in a town is that in a street standing waves are apt to be set up; when driving through such a street one therefore passes through maxima and minima, and the quicker these follow each other — the smaller the wavelength — the less does intelligibility suffer.

Intermittent working

If a call is to be heard at once, the receiver in a mobile radio station must be continuously in the stand-by position. After a call has been received, or when another station has to be called up, the installation is changed over to transmission, mostly by means of a switch built into the microphone handle. This changing over is then repeated as the conversation proceeds to and fro. Since as a rule the intervals of rest between talks are much longer than the talks themselves, in practice the transmitter is working only a fraction of the time, while the receiver is working almost continuously. Thanks to these long intervals, for some transmitting valves operating conditions are allowed which permit of a somewhat larger output than would be permissible for continuous working.

Number of stages of the transmitter

Notwithstanding the relatively short working time of the transmitter, it is necessary to aim at the least possible power consumption, i.e. at a high total efficiency of the transmitter. We shall presently deal further with the steps that have been taken in the new transmitting valves in order to limit the losses as far as possible, but another equally important factor upon which the total efficiency depends is the number of stages required between the aerial and the quartz crystal determining the carrier frequency.

This number of stages is closely related to the system of modulation. Two systems, amplitude modulation and frequency modulation, are to be considered, both of which are applied in mobile transmitters; it is not the place here to explain why in one case amplitude modulation is employed and frequency modulation in another.

Where amplitude modulation is employed one has a constant carrier frequency, which of course has to lie in one of the frequency bands allotted. Now the frequencies of these bands are so high that they cannot be generated directly by means of a crystal. Owing to the fragility of the crystal, especially when it is exposed to the shocks occurring in a mobile transmitter, about 0.15 mm is the least thickness it may have, and this corresponds to a natural frequency of about 20 Mc/s [2]). For a carrier frequency of say 320 Mc/s it is therefore necessary to apply at least a 16-fold frequency multiplication. In such cases it is advantageous to use double valves with the two electrode systems, mounted in one envelope, connected in cascade. By frequency doubling in each system no more than two of these double valves are then required to multiply the input (crystal) frequency 16 times.

In addition an output valve and a modulator valve are needed and one or two stages of A.F. amplification between the microphone and the modulator.

With frequency modulation a system can be followed, for instance, as described by Braak [3]), where the microphone voltage brings about a phase shift between two currents having the frequency of the quartz crystal, in such a way that the phase φ of the sum of these currents varies according to the equation

$$\varphi = \omega_0 t + a \sin 2\pi \nu t$$

where ω_0 = angular frequency of the crystal, t = time, a = amplitude of the phase shift (phase sweep), ν = frequency of the incident sound at the microphone. Corresponding to the phase modulation of the total current is a frequency modulation, the instantaneous value ω of the varying angular frequency being defined by

$$\omega = \frac{d\varphi}{dt} = \omega_0 + a \cdot 2\pi\nu \cos 2\pi\nu t\,,$$

so that the instantaneous value $f = \omega/2\pi$ of the modulated frequency is:

$$f = f_0 + a\,\nu \cos 2\pi\nu t$$

($f_0 = \omega_0/2\pi$). The sweep of this frequency is $a\nu$. For undistorted reproduction the frequency sweep

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[2]) Crystals are also being used, especially in the U.S.A. and in Great Britain, which oscillate with (practically) a multiple of the natural frequency (see, e.g., the article by W. Parrish in this number, p. 166), so that frequencies higher than 20 Mc/s can be generated with still crystals.

[3]) D. J. Braak, Mobile radio equipment, type SRR 192, Communication News **10**, 120-125, 1949 (No. 4).

has to be proportional to the intensity of the sound and independent of the audio frequency ν, which means to say that the phase sweep α has to be proportional to the sound intensity and inversely proportional to ν [4]).

If an n-fold frequency multiplication is applied between the modulating stage and the output stage the sweep of the aerial frequency will therefore amount to $n\alpha\nu$. For transmitters which are modulated only with speech — as is the case with mobile transmitters — this sweep has been limited by international agreement to 15,000 c/s, and in order to derive the utmost benefit from frequency modulation this sweep has to be used to the full. To prevent prohibitive non-linear distortion the phase sweep α has to be limited to an angle of about 0.5 radian. Hence the frequency multiplication required to get an aerial frequency sweep of 15,000 c/s with the maximum phase sweep, i.e. at the lowest audio frequency ν occurring in telephony (300 c/s), and with full phase modulation ($\alpha \approx 0.5$ radian), is

$$n \approx \frac{15{,}000}{0.5 \times 300} = 100\,.$$

(Since this value of n is greater than that found in the case of amplitude modulation, with frequency modulation the mechanical strength of the crystal is not a determining factor.)

A frequency multiplication of about 100 can be obtained with three double valves, for instance as follows: $(3 \times 2) \times (2 \times 2) \times (2 \times 2) = 96$. For the first of these valves a low-power type suffices, which need not be made for particularly high frequencies, e.g. the double triode ECC 40, but for the third valve (and possibly also for the second one), in which the frequency is much higher than the crystal frequency, it is preferable to use one of the double tetrodes of the type QQC 04/15 or QQE 06/40 [5]) to be described in this article. The same types of valves can also be used as output valves (with either frequency or amplitude modulation), though then the two systems have to be connected in push-pull instead of in cascade; we shall revert to this later.

Choice of the type of valve

A tetrode, rather than a triode or a pentode, has been chosen because of a number of considerations, most of which apply in general to all transmitting valves for the frequency range in question, without being limited to valves for mobile transmitters. These considerations are the following.

At high frequencies a triode is in two respects at a disadvantage compared with a screen-grid valve (tetrode or pentode); in the first place a triode requires a greater driving power [6]) and thus also necessitates a larger number of amplifying stages, whilst in the second place with screen-grid valves, compared with triodes, it is possible to work with fairly high frequencies without (external) neutralization, i.e. compensation of undesired feedback such as arises, for instance, owing to the capacitance between anode and control grid.

That is why a screen-grid valve has been chosen. Of the two kinds to be considered, the tetrode and the pentode, the former is to be preferred at very high frequencies, since the absence of the third grid permits of a smaller anode capacitance, i.e. the capacitance between the anode and the other electrodes together. The absence of the third grid, however, makes it necessary to take certain steps for preventing any secondary electrons emitted by the anode reaching the screen grid; the purpose of the third grid (suppressor grid) in a pentode is to bring about between the anode and the screen grid a potential minimum suppressing the undesired secondary emission. Such a potential minimum, however, can be obtained by other means too, by giving a tetrode system such dimensions that, with the normal working currents and voltages, between the anode and the screen grid a concentration of space charge is brought about which provides the desired potential minimum [7]).

Furthermore, the secondary emission itself can be counteracted by coating the anode with a layer of a material from which the electrons do not easily emerge (see the article quoted in footnote [7])). Both these measures have been applied in the new types of transmitting valves.

The anode capacitance, already small owing to the absence of a third grid, can be still further reduced by dividing the electrode system into two

[4]) The latter can be reached to a sufficient approximation by means of a correcting network between the microphone and the phase modulator.

[5]) Here the letter Q means tetrode, QQ double tetrode, C directly-heated oxide-coated cathode, E indirectly-heated oxide-coated cathode. The figures 04 and 06 signify that the valve is intended for a supply voltage of 0.4 or 0.6 kV respectively, while the numbers 15 and 40 denote the order of the output in watts (as will presently be seen, in suitably chosen circuits these valves can yield much higher outputs than 15 or 40 W).

[6]) See J. P. Heyboer, Five-electrode transmitting valves (pentodes), Philips Techn. Rev. 2, 257-265, 1937, in particular pp 260 and 261.

[7]) See, e.g.: J. L. H. Jonker, Secondary emission in output valves, Philips Techn. Rev. 10, 346-351, 1948, fig. 3, curve *1*. The difficulty therein mentioned, which makes this method unsuitable for output valves of low-frequency amplifiers, applies in a much less degree for transmitting valves.

parts and connecting the two halves to the external circuits in push-pull. With given total dimensions of the electrodes (thus with a certain permissible heat dissipation in the valve) and certain distances between the electrodes, the input and output capacitances are then four times smaller, since the partial capacitances are in series instead of in parallel.

When the two electrode systems of the double valve obtained by this division are connected in cascade instead of in push-pull the same type of valve can advantageously be used also for frequency multiplying, as we have seen above.

Transmitting valves with two electrode systems in one envelope have in fact been known some fifteen years already. In the old designs the electrodes not carrying any high-frequency voltage (the cathodes and the screen grids) were connected in pairs by short wires or strips, and the centres (neutral points) of the interconnections were led out through the envelope, as were each of the two control grids and the two anodes. This is illustrated in *fig. 2a*. A difficulty arising with these valves was the self-inductance of the interconnection of the cathodes and of the screen grids (fig. 2*b*). At very high frequencies the influence of these self-inductances is not to be ignored. The self-inductance between the cathodes causes an undesired inverse feedback and constitutes a positive contribution towards the input damping [8]), so that in order to yield a certain output the valve needs a larger driving power. The influence of the self-inductance between the screen grids is manifested as a negative damping [9]), which is zero only at one certain frequency and at other frequencies may assume such a value that in order to avoid self-oscillation some form of neutralization or other has to be applied, especially for valves with a high mutual conductance. Below the frequency just referred to this neutralization can be brought about by introducing a capacitor of a certain value between each anode and the control grid belonging to the other anode. Above that frequency these capacitors have to be connected between each anode and its corresponding control grid.

How these complications have been avoided in the new designs of double tetrodes will be shown in the next section.

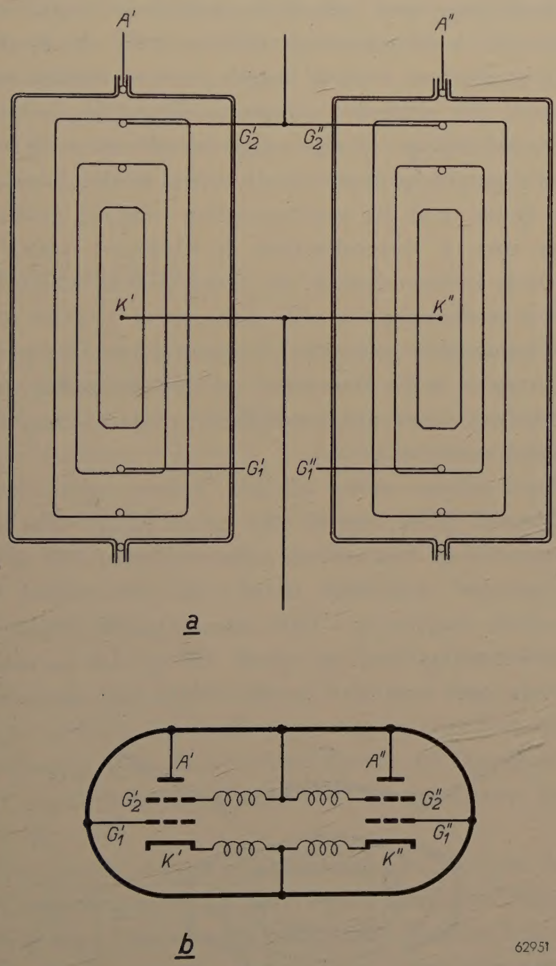

Fig. 2. (*a*) Cross section of a double tetrode of the old design. K', K'' cathodes; G_1', G_1'' control grids; G_2', G_2'' screen grids; A', A'' anodes. In the equivalent diagram (*b*) the stray self-inductances in the leads of the cathodes and screen grids are indicated. (The stray capacitances that are also present are not indicated.)

The double tetrode QQE 06/40

Construction

A double tetrode of the type QQE 06/40, illustrated in *fig. 3*, contains one indirectly heated, nickel cathode in the form of a roughly rectangular tube (*fig. 4*). Only the long, slightly convex sides of this tube are coated with an emitting material, so that really the tube has two cathodes interconnected by the shorter sides of the rectangular body. The self-inductance of these short and wide "connecting strips" connected in parallel is so small that even at frequencies of 400 Mc/s the aforementioned effect of self-inductance in the cathode interconnections is quite negligible. The resistance of this connection is likewise very small, even at high frequencies, due partly to the fact that the working temperature of the cathode lies above the Curie point of nickel, so that permeability is 1 and consequently there is but little skin effect.

[8]) M. J. O. Strutt and A. van der Ziel, A variable amplifier valve with double cathode connection suitable for metre waves, Philips Techn. Rev. 5, 357-362, 1940.

[9]) W. G. Wagener, 500-Mc transmitting tetrode design considerations, Proc. Inst. Rad. Engrs. 38, 611-619, 1948.

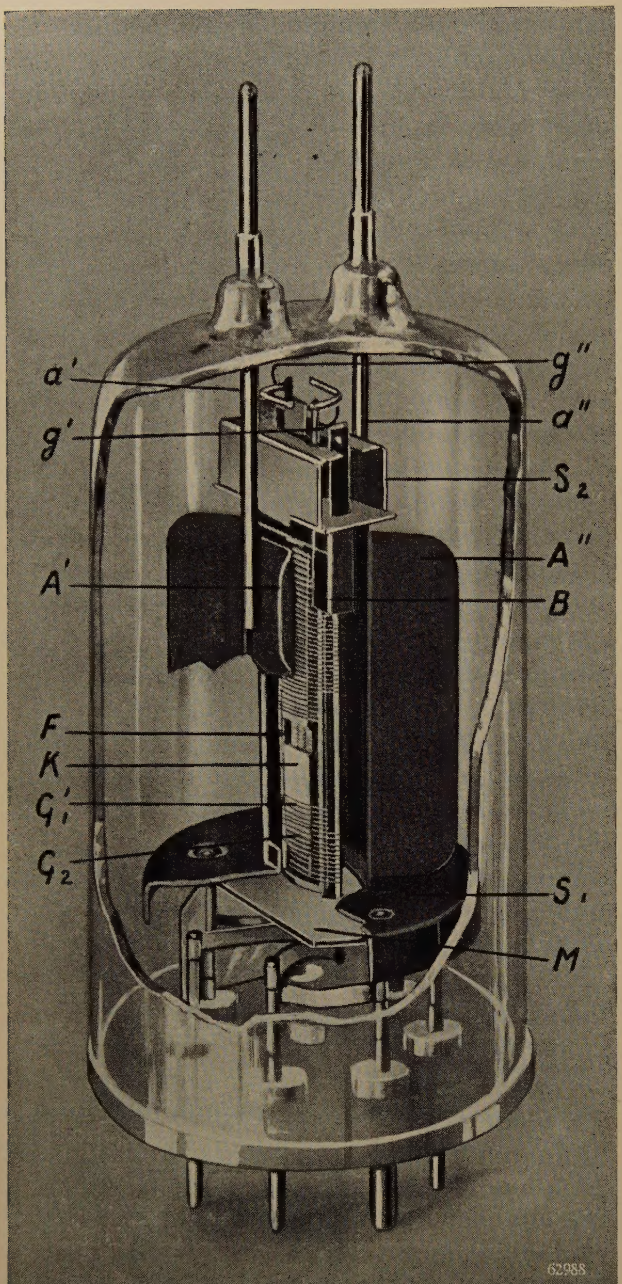

Fig. 3. Photograph of the double tetrode QQE 06/40 cut open to show the inside. K is one of the emitting cathode surfaces, F one of the filaments, G_1' one of the control grids, G_2 the screen grid, A', A'' the anodes, B one of the beam-plates, S_1 the lower screen screening the mica plate M in which the electrodes are fixed. The rods g', g'' are connected to the grids G_1' and G_1'' respectively and together with the anode poles a'' and a' form neutralizing capacitors. The box S_2 connected to the cathodes and the plates B screens the neutralizing capacitors from the electrode systems.

The cathode surface is heated by two filaments inside the cathode body.

A short distance away from and facing each of the emitting surfaces are the two control grids made in the form of a ladder. The extremely thin horizontal grid wires are curved so that when they expand the distance between the grid and the cathode is not reduced and thus there is no risk of short-circuiting.

The control grids are made of molybdenum wire plated with a thin layer of gold. This plating reduces the resistance at high frequencies and minimizes the risk of thermionic emission from the grid.

One single screen grid is placed around the system comprising the cathode and the two control grids. This screen grid is made of windings fixed to two supporting rods. This construction avoids the necessity of separate leads for the two halves of the screen grid and thus also completely eliminates the self-inductance of those leads. But at the same time the advantage is lost of the compensating effect of that self-inductance in a certain frequency range with regard to the positive feedback of the anode upon the control grid belonging to it, and in the absence of such compensation the valve might tend to oscillate. This tendency to oscillate is counteracted in the QQE 06/40 by introducing two small neutralizing capacitors. Each of these capacitors is formed by the lead of one anode and a short length of wire welded onto one of the extended support rods of the control grid belonging to the other anode (see fig. 3). The capacitance is practically equal to that between an anode and its corresponding control grid. In this way a neutralization is obtained which is entirely independent of the frequency at which the valve is working.

The anodes are molybdenum plates coated on both sides with zirconium powder to reduce the secondary emission coefficient and to improve radiation of heat.

On either side of the screen grid is a U-shaped plate, called the beam-plate, which is connected to the cathode, the object of this being to prevent deflection of the electrons from the shortest trajectory. Thus these plates assist in concentrating such a space charge between the screen grid and the anodes that the secondary

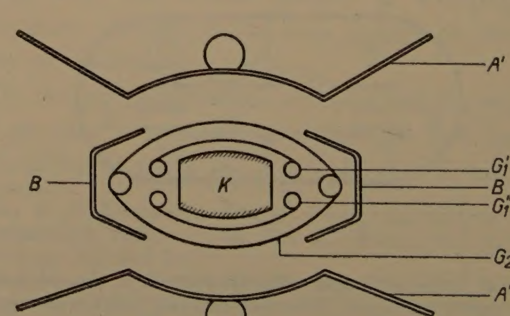

Fig. 4. Horizontal cross section of the QQE 06/40 valve. For the meaning of the letters see fig. 3.

electrons cannot reach the screen grid when the anode current is large.

Since the beam-plates prevent them from following long trajectories, all the electrons have about the same and the shortest possible transit time. Without such a measure there would be differences in transit time and at very high frequencies these differences would adversely affect the efficiency of the valve.

As is the case with receiving valves, in the QQE 06/40 a mica disc is used for fixing the mutual positions of the electrodes. This plate is screened from the strong electric field of the anodes, so that there are practically no dielectric losses in the mica, which again makes for good efficiency.

Except for the anodes, whose leads and supporting rods pass through the top end of the hard-glass envelope (fig. 3), the rest of the electrode system is mounted on a base of sintered glass [10]), into which seven rods of molybdenum have been fused. Three of these rods extend farther into the envelope than the others and carry the screening of the mica plate. This screening plate together with the beam-plates welded onto it form a framework, in which the cathode and the grids are fixed. Thus an exceptionally rugged construction is obtained, which makes the valve resistant to severe shocks.

Electrical properties

As already mentioned, the cathode is heated by means of two filaments interconnected at one end. These filaments can be connected either in parallel or in series as required, in view of the fact that some motorcars have 6 V batteries while others have batteries of 12 V; the total consumption is thus 6.3 V, 1.8 A or 12.6 V, 0.9 A respectively.

The D.C. anode voltage is max. 600 V at frequencies below 250 Mc/s, max. 400 V at frequencies above 300 Mc/s and max. 500 V in the intermediate frequency range; the screen-grid voltage is 250 V. These voltages can be derived from a rotary converter or from a transformer working together with a vibrator. The dissipation of each of the anodes may amount to 20 W and that of the screen grid to 7 W.

The input capacitance measured between the two control grids is about 6.7 pF, while the output capacitance between the two anodes is about 2.1 pF.

The feed-back of each anode upon its corresponding control grid is quite insignificant, thanks to the built-in neutralizing capacitors, so that the QQE 06/40 cannot oscillate unless feedback is purposely applied externally. In amplifiers the absence of internal feedback ensures a high degree of stability Owing to the self-inductance and the resistance of the cathode lead being extremely small, only a small driving power is needed, which can be taken, for instance, from an EL 41 valve.

The highest frequency at which the QQE 06/40 can still operate with a reasonable efficiency is about 430 Mc/s (wavelength 0.70 m). It can work at still higher frequencies but then the power gain is no greater than that of an equivalent triode.

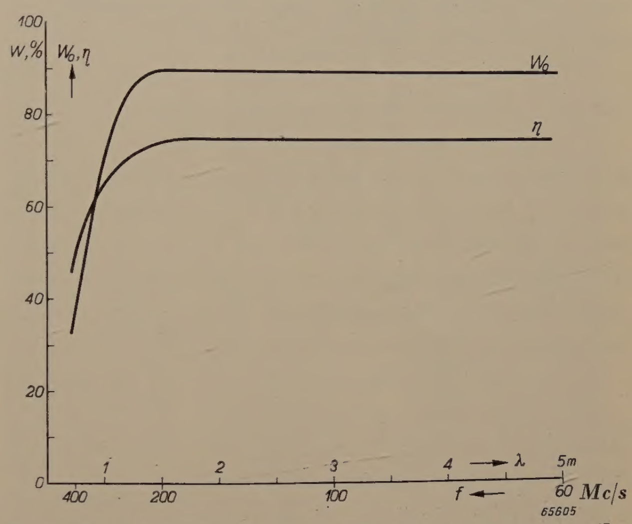

Fig. 5. Output W_0 and efficiency η [11]) of the QQE 06/40 valve as functions of the wavelength λ and the frequency f.

In *fig. 5* the output and the efficiency [11]) have been plotted as functions of the wavelength. It is seen, for instance, that at frequencies below 200 Mc/s 90 W can be generated with an efficiency of about 75%, and that at a frequency of 300 Mc/s these figures are 70 W and 65% respectively.

The double tetrode QQC 04/15

Construction

In cases where a lower output suffices there is need of a smaller and less expensive valve, and it is with a view to meeting this need that the QQC 04/15 valve has been developed, an illustration of which is given in *fig. 6*.

The construction is analogous to that of the QQE 06/40 in that the QQC 04/15 is likewise a double tetrode with one screen grid common to both the electrode systems (see the cross section in *fig. 7*).

[10]) E. G. Dorgelo, Sintered glass, Philips Techn. Rev. 8, 2-7, 1946.

[11]) As usual, here efficiency is understood to be the ratio of the output W_0 to the D.C. power fed to the anodes.

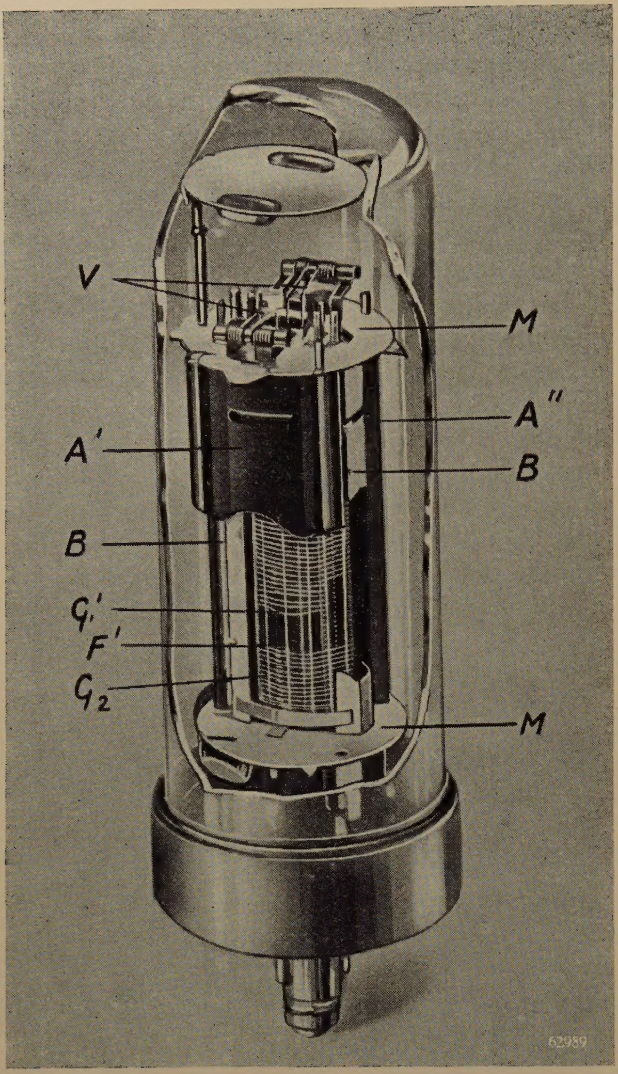

Fig. 6. Photograph of the double tetrode QQC 04/15 cut open to show the inside. F' one of the directly heated cathodes, G_1' one of the control grids, G_2 screen grid, A', A'' anodes, B beam-plates, M mica disc, V springs keeping the filaments stretched.

One point of difference, however, lies in the cathodes, which in this construction are directly heated and each consists of a V-shaped, oxide-coated filament. Such a cathode requires less heating power than that needed for a corresponding indirectly-heated cathode, whilst also the thermal inertia is much less. The cathode of the QQC 04/15, which consumes 4.3 W, reaches its working temperature 1.5 seconds after switching on, so that, in order to avoid unnecesary draining of the battery, the filament current can quite well be switched off while the transmitter is not working.

The two V-shaped filaments are connected in series and the common point is connected to a base pin.

A directly heated cathode causes a greater input damping than an indirectly heated one, and for this reason it was not necessary to use neutralizing capacitors in the QQC 04/15, but on the other hand a relatively larger driving power is needed.

The envelope is made of soft glass. This, it is true, cannot withstand such a high temperature as the hard glass of the QQE 06/40, but it has the advantage that the valve can be manufactured on the machines equipped for the mass production of receiving valves. Thus the QQC 04/15 has the appearance of a receiving valve (fig. 6), namely that of one of the key type.

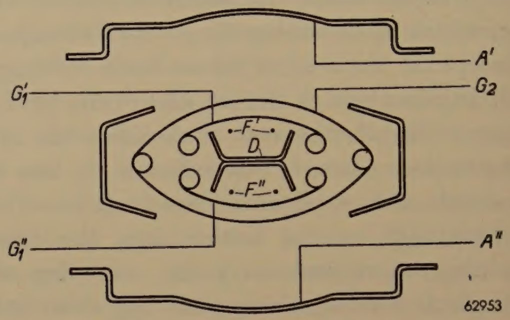

Fig. 7. Horizontal cross section of the QQC 04/15 valve. F', F'' cross section of the two V-shaped, directly heated cathodes, between which is a screen D. The other letters are as indicated in fig. 4.

A difference compared with normal receiving valves lies in the base pins, which are of chrome iron and coated over their entire length with a thin layer of copper, in such a way, of course, that the leads are vacuum-tight. The resistance of this layer at very high frequencies is much less than that of non-coated pins [12]).

The QQC 04/15 is well able to withstand the mechanical shocks occurring in automobiles and trains, just as well as the other valves used in the transmitter and in the receiver.

Electrical properties

At a voltage of 6.3 V the filament current of the QQC 04/15 is 0.68 A. When a 12 V battery is used two of these valves can be connected in series.

The D.C. anode voltage is max. 400 V and the screen-grid voltage 200 V. Each of the anodes has a dissipation of 8 W and the screen grid 7 W.

When used in push-pull the QQC 04/15 has an input capacitance of 5.7 pF and an output capacitance of 1.7 pF. The capacitance between an anode and its corresponding control grid is 0.05 pF.

[12]) Cf. K. Rodenhuis, Two triodes for reception of decimetric waves, Philips Techn. Rev. 11, 79-89, 1949 (No. 3), in particular p. 81.

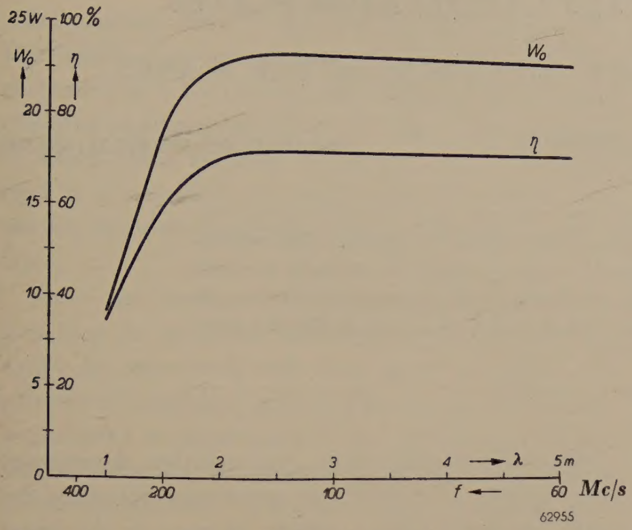

Fig. 8. Output W_0 and efficiency η [11]) of the QQC 04/15 valve plotted as functions of the wavelength λ and the frequency f.

Fig. 8 shows the output and efficiency of this valve as functions of the wavelength. The output at frequencies of 150 and 300 Mc/s, for instance, is respectively 22.5 W and 9 W, with efficiencies of over 70% and 34%.

Mobile installations with the new valves

Philips' Telecommunication Industry (Hilversum, Holland) is turning out a mobile installation, type SRR 192, with the transmitter and the receiver built together in a metal case that can be carried in the boot of a car (*fig. 9*). The control panel, the microphone and the loudspeaker are mounted in front of the driver's seat. The whole of the installation is tropic-proof.

The transmitter has a QQE 06/40 as output valve and offers the choice of two frequencies within a range of 300 kc/s. Frequency-multiplication is obtained by means of three EF 42 valves and one EL 41 valve. Frequency modulation is applied.

When this apparatus is used for a fixed station it can be supplied from the A.C. mains. Between two of these sets, one mobile and the other installed at a fixed point with an aerial 25 m above the ground, in open country a range of 20 to 25 km can be covered.

For further particulars reference is made to the article quoted in footnote [3]).

One of the authors of the present article (P.Z.) has designed a smaller mobile installation which likewise works on the frequency-modulation system and has a carrier frequency of 186.24 Mc/s [13]). This employs four QQC 04/15 valves, one of which in the output stage and three for frequency multiplication.

[13]) This design is fully described in "QQC 04/15 Double Tetrode for Mobile Transmitting Equipment", a technical publication issued by the Electronic Tube Division of Philips, Eindhoven, Holland.

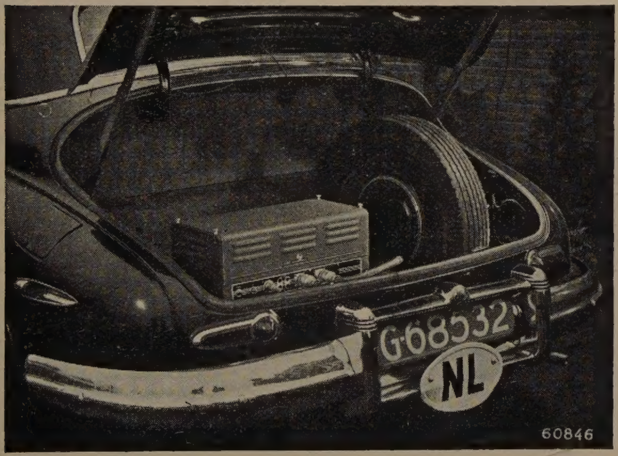

Fig. 9. Mobile transmitter and receiver, type SRR 192, in the boot of a motorcar.

Summary. Following upon some introductory remarks concerning mobile radio stations such as are now being used for communication between automobiles or trains (mutually and with a fixed point), a description is given of two transmitting valves that have been specially developed for this purpose. These are both double tetrodes (types QQE 06/40 and QQC 04/15) in which the two electrode systems are so constructed that the screen grids form mechanically one whole, by this means completely avoiding the complications arising from stray self-inductance in separate screen-grid leads. In an output stage the two electrode systems of a valve are preferably used in push-pull. For frequency multiplication they can be connected in cascade. The QQE 06/40 type has an indirectly-heated cathode of a special construction, owing to which only a very little driving power and thus few stages are needed. Two built-in neutralizing capacitors provide for good stability. The cathodes of the QQC 04/15 type of valve are directly heated and consequently there is little thermal inertia. At frequencies of 200 Mc/s and below the QQE 06/40 can generate 90 W with an efficiency of about 75%, and at 300 Mc/s the output is 70 W with 65% efficiency. For the QQC 04/15 these figures are respectively about 22.5 W with over 70% and 9 W with 34% efficiency.

THE MANUFACTURE OF QUARTZ OSCILLATOR-PLATES

III. LAPPING AND FINAL FREQUENCY ADJUSTMENT OF THE BLANKS

by W. PARRISH *).

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A manual sweeping lap motion is replaced by the cycloid motion of a machine. The mechanical abrasion by the grains of an abrasive material is supplemented by the molecular corrosion of an etching solution. These are the principles which have made it possible to increase the production of quartz oscillator-plates a hundred or a thousand times and to give the plates permanently the desired properties.

A quartz plate intended for the stabilization of the frequency of a short-wave transmitter working on a wavelength between about 3 m and 150 m is usually cut from the crystal in the orientation of the so-called AT or BT cut, and is made to vibrate

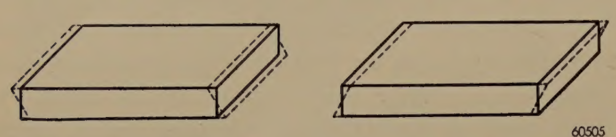

Fig. 1. Oscillator-plates according to an AT or BT cut are square, with sides from 3 to 50 mm long (normally about 12 mm). These plates are made to vibrate in a thickness shear mode. Two opposite phases of the deformation are shown by dotted lines.

in a thickness-shear mode (*fig. 1*). The characteristic frequency of plates vibrating in this way depends principally upon their thickness and is inversely proportional to it. The relation between frequency f and thickness D ($f \times D$ = constant = K) is represented graphically in *fig. 2* for the two cuts mentioned. In practice, plates are used with a thickness varying from about 0.8 mm (AT plate with a frequency of 2 Mc/s) to about 0.3 mm (BT plate with a frequency of 9 Mc/s). For transmitters with frequencies higher than 9 Mc/s thinner plates are not usually used, but a thick plate is allowed to vibrate with an odd harmonic of the mode of vibration illustrated, or oscillator circuits with frequency multiplication are used [1]).

Since it follows from the relation mentioned that $\mathrm{d}f/\mathrm{d}D = -K/D^2$, it is obvious that in the case of thin plates a slight change in thickness causes a large change in resonance frequency. In the case of a BT-cut crystal with f = 9 Mc/s a change in thickness of for instance 10^{-5} mm corresponds to a frequency change of 320 c/s. A transmitter which is stabilized by the 11th harmonic of this crystal, with the deviation in thickness mentioned, would operate more than 3 kc/s away from its nominal frequency (not exactly $11 \times 0.320 = 3.52$ kc/s, since the "harmonics" of a vibrating plate are not in exact integer ratios to each other). In order to be able to use all the plates produced immediately for definite channels in the intended wavelength region (the channels are usually about 100 kc/sec wide at the highest frequencies considered), the required frequency is given with a tolerance of for example 500 c/s. The thinnest blanks must then be finished to have the necessary thickness within an accuracy of about 2×10^{-6} mm, in order to be suited for use in the 11th harmonic.

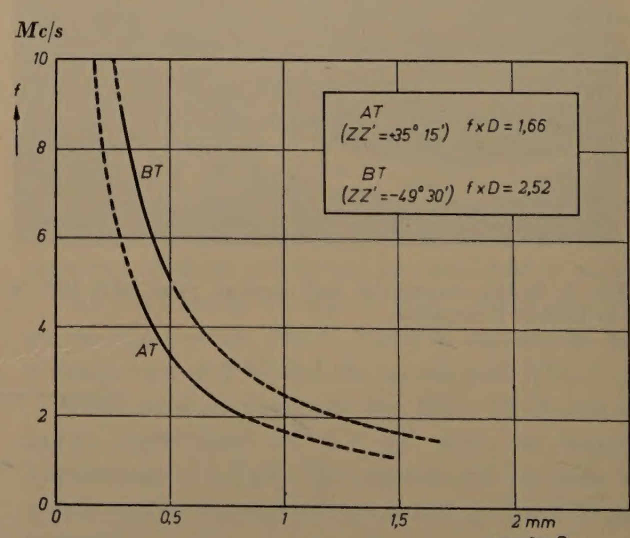

Fig. 2. Relation between resonance frequency f and thickness D of quartz plates according to the AT and BT cut.

*) Philips Laboratories, Inc., Irvington-on-Hudson, N.Y., U.S.A.

[1]) The lower limit of 0.3 mm for the thickness was imposed by the requirement of reliability in mobile equipment for wartime applications, which could be exposed to severe shocks. To-day's mobile transmitters are equipped also with thinner plates, down to about 0.15 mm. Lapping of blanks is possible to even smaller thicknesses, of about 0.06 and even 0.03 mm. — For the position of the AT, BT and other cuts in the crystal as well as for the manner in which a plate can be cut in the desired direction see two preceding articles in this periodical: W. Parrish, The manufacture of quartz oscillator-plates, I. How the required cuts are obtained, Philips Techn. Rev. **11**, 323-332, 1949 (No. 11), and II. Control of the cutting angles by X-ray diffraction, Philips Techn. Rev. **11**, 351-360, 1949 (No. 12).

In practice this is done in the following way. The blanks are sawed out of the crystal with a thickness of 1 to 1.2 mm and then lapped to the required thickness of 0.3 to 0.8 mm. The fact that so much must actually be lapped off — or rather that it is necessary to begin with blanks so much thicker than the finished plates — will become clear later.

Since the resonance frequency is so sensitive to a change in thickness and because frequencies can easily be measured with very great accuracy, the process of lapping a quartz plate is not checked by a precision measurement of the thickness reached, but directly by a determination of the resonance frequency obtained. Therefore, in the art one speaks of "lapping off a certain number of cycles" — which means that the thickness is lapped off until the frequency has risen by that number of c/s.

In order to obtain a crystal of good activity, i.e. one which upon weak excitation vibrates with a reasonably large amplitude and which dissipates little energy, the surface must be smooth and completely without flaws and the upper and lower surfaces of the crystal must be lapped so that they are exactly parallel. At the edges, however, and especially at the corners the thickness must be one to several microns less than in the center part; see the much exaggerated sketch in *fig. 3*. This shape has been found empirically to be favorable for the avoidance of the simultaneous occurrence of undesired modes of vibration of the plate, which would have an unfavorable effect on its activity.

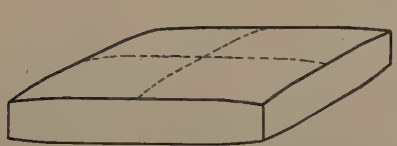

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Fig. 3. "Contour" of quartz plates required for high "activity". The deviations from plane parallelism are drawn very much exaggerated.

The lapping of a blank can be done by hand, by pressing the blank gently against a glass surface covered with abrasive and moving it with a sweeping motion over the glass, preferably in the form of figure eights (8). The desired contour can also be given to the blank by distributing the pressure in a suitable way during the lapping. The blank is first lapped for a time with two fingers pressing on diagonally opposite corners and then for a time with two fingers on the other two corners. Care must at the same time be taken that the blank travels uniformly over all parts of the glass surface so that the latter, which is of course also somewhat lapped off, may remain perfectly flat.

For the mass production of quartz plates such as had to be organised in 1942 in the United States at very short notice because of the necessities of the war, lapping by hand was naturally very undesirable and thus mechanical methods of lapping were sought. A solution which, as far as speed and precision obtained are concerned, gives excellent results was found in the planetary lap machine. This machine was developed by G. C. Hunt and P. R. Hoffman [2]). The lapping procedures with this machine have been critically investigated and further developed by the North American Philips Co. in a pilot plant set up for that purpose, and they were being used at the end of the war in numerous quartz plate industries [3]).

The planetary lap machine

Construction

The principle of the planetary lap machine will be discussed with reference to *fig. 4*. On a stationary circular iron lap plate 30 or more blanks to be lapped are laid in work holders of gear-wheel form as shown in the figure; the square blanks lie loosely in the pentagonal holes of the holders. By means of an inner gear turning in a central bore of the plate and an outer ring gear rotating around the circumference of the plate the work holders are brought into a complex rotating motion around their own centres and around the centre of the lap plate (hence the name of the machine; cf. also the planetary driving mechanism which was used for example in some of the first steam engines). Each blank describes a broad sweeping lap motion over the plate, which is equivalent to the motion in hand lapping.

The work holders are slightly thinner than the quartz plates to be lapped. A second lap plate is laid on top of the arrangement, so that it rests upon the upper side of the blanks, and is held loosely in position by a slotted arm (it thus remains stationary; see *fig. 5*). A suspension of the abrasive — which will be dealt with later in detail — in a lubricant is introduced between the two lap plates via feed holes in the top plate. The abrasive accumulates in the serrations cut into the lapping

[2]) G. C. Hunt, U.S. Patent No. 2,314,787, March 23, 1943; P. R. Hoffman, U.S. Patent No. 2,308,512, June 19, 1943.

[3]) A survey is given in W. Parrish, Machine lapping of quartz oscillator-plates, American Mineralogist **30**, 389-415, 1945. See also: W. L. Bond, Chap. IX in R. A. Heising, Quartz crystals for electrical circuits, D. van Nostrand, New York 1946.

surfaces of the two plates. Sweeping over the serrations all 30 blanks are lapped simultaneously and uniformly, upper and lower surfaces alike.

Closer examination of the movement of the blanks being lapped

It will immediately be clear to the reader that an enormous production can be obtained with such a machine, and also that the requirement of parallelism of the two sides of the crystal can easily be met in this way. It will be less obvious however that with the lap machine alone, without further treatment, the typical contour shown in fig. 3 can be obtained. In order to understand this we must consider the movement of the blanks in the lapping process more closely. Apart from this, it is in any case worth while to examine this peculiar motion.

Let us first consider the case in which the inner and outer gears rotate in the same direction at the same number of revolutions per unit time. In that case the work holders will move as if they were rigidly connected to inner and outer gear. This amounts to the same thing as if the work holders were stationary and the two lap plates slid above and below them. In various respects the result of this motion will not correspond to what is desired.

In the first place the outer crystals cover a longer distance in the abrasive than the inner ones and are thus lapped thinner. It might seem that this would not be objectionable: it would mean one lap would produce a series of crystals of different thicknesses which would require sorting later as to thickness for the different channels (frequency regions). Although sorting and classification is

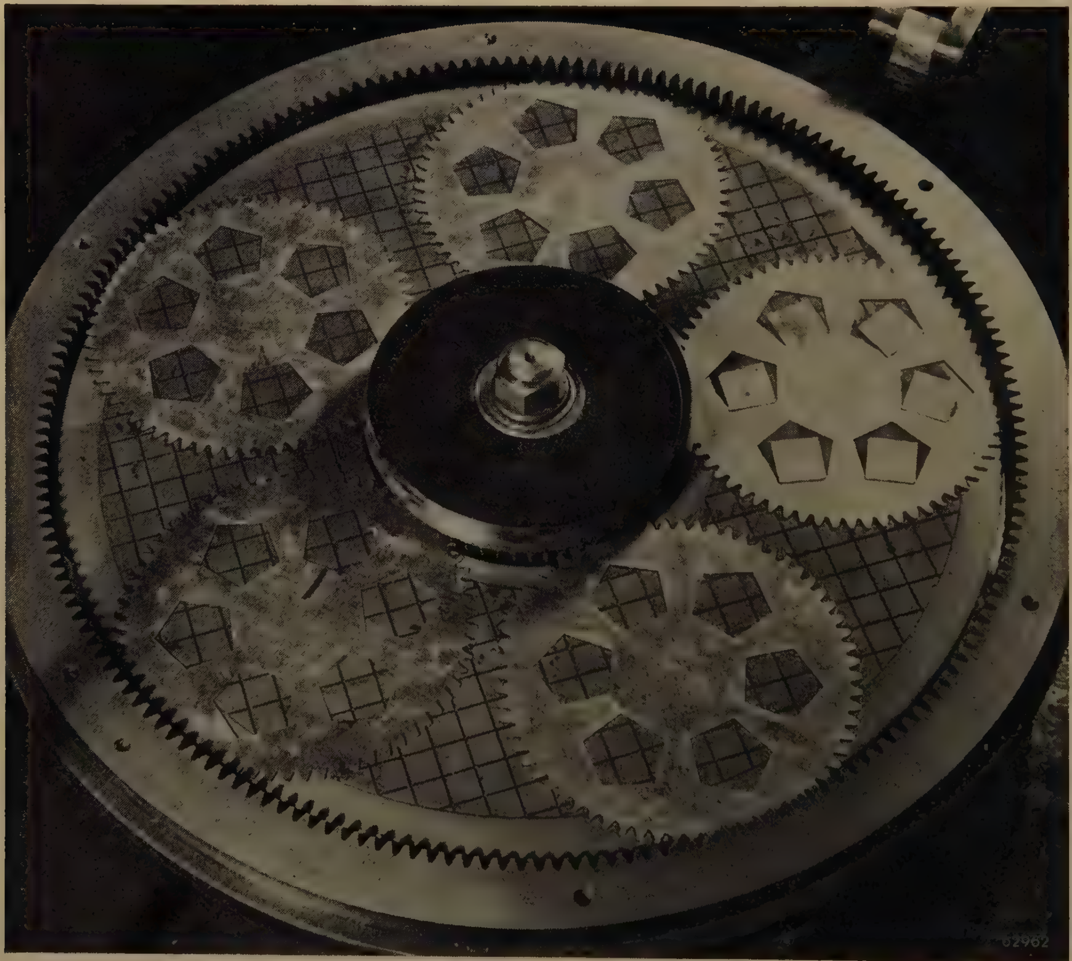

Fig. 4. The planetary lap machine. The serrated lap plate is stationary, the outer ring gear and inner gear rotate. The five gear-shaped work holders, each of which can hold six quartz blanks for lapping in the pentagonal holes (only one of the holders is filled) describe a complex motion over the plate. A second lap plate is laid on top of the arrangement so that the thirty blanks are lapped on both sides simultaneously. For smaller oscillator-plates holders with 8 and 11 holes are used, so that a lap then consists of 40 or 55 plates, respectively.

possible, such a method would be irrational. It would be necessary to keep large stores of quartz crystals on hand and this would mean much administration, etc. For smooth production it is on the contrary much better to be able to make all the crystals of a single lap for a given channel, which means that the frequency spread of the 30 or more crystals at the end of the lap should not be more than 10 to 15 kc/s [4]).

surface of the lower lap plate, also executes a rotation about its own centre. The resulting relative motion can for our purposes best be represented as if the holders, rotating around their own centres, remain stationary while the two lap plates slide along them above and below. In this motion each blank travels periodically back and forth between the inner and outer edge of the lap plates. All the blanks and also the whole surface of the lap plates

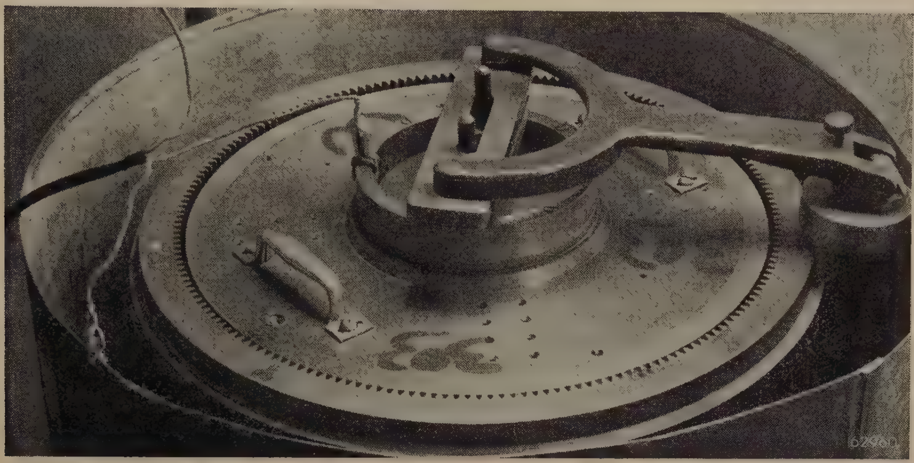

Fig. 5. Planetary lap machine in use. On top of the lap plate with work holders as shown in fig. 4 the second lap plate is laid and floats upon the crystals. The slotted arm prevents this plate from turning with the holders. The abrasive suspended in a lubricant is fed through the holes in the upper plate and flows between the two lap plates. The outer metal shield catches the spattering abrasive suspension. The significance of the electrical connections is explained below.

In the second place — and this is worse than a mere inconvenience — the simple circular motion would by no means lead to the desired contour of the crystals. The upper and lower surfaces would not be parallel, but all the crystals would be wedge-shaped: in rotating, the same edge of the blanks would always come into contact with the fresh abrasive and their surfaces would therefore be lapped off more on that edge than on the opposite edge.

In the third place the iron lap plates would not long remain flat, since the stronger lap action near the circumference would naturally also affect the lap plates.

Let us now compare this with the actual motion of the blanks. The inner gear is made to rotate faster than the outer ring gear, about 3 times the number of revolutions (in the same direction). The result is that each work holder with its six blanks in addition to the "translation" over the surface of the lower lap plate, also executes a rotation about its own centre.

are now lapped to practically the same extent (we shall consider the statistical fluctuations in this below).

A further feature of the actual motion is that no wedge-shaped crystals will be produced. In fact, due to the rotation of the work-holder each of the four edges of a blank gets its turn in receiving the fresh abrasive. Moreover, each blank also "spins" around its own centre, in the pentagonal hole of the work holder, as is explained in *fig. 6* and the accompanying legend; hence, the "turns" of the four edges are not correlated with invariable positions of the work holder, but, on the contrary, each edge gets its turn successively in all possible positions of the holder (with the corresponding, more or less widely differing relative velocities of the blank and the lap plates!). Thus, all four edges of the blank are assured of a completely identical treatment and fine plane-parallel crystal plates are obtained.

As regards the special contour of the oscillator-plates, owing to the motion described the blanks automatically will acquire a form similar to that

4) For BT cuts of 6-8 Mc/s. This tolerance is much larger than that mentioned in the beginning, because a final frequency adjustment follows the mechanical lapping. We shall return to this in the last section.

drawn in fig. 3. In fact the lapping action is stronger at the edges — which receive fresh abrasive — than in the centre, and strongest at the corners (which belong to two edges). Therefore, the blanks at the edges and especially at the corners are lapped

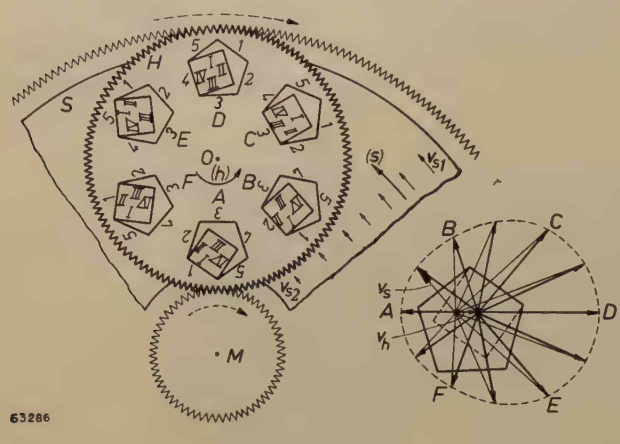

Fig. 6. The relative motion described by a work holder H with respect to the lap plate S can be built up of two components: the work holder revolves about its own stationary centre O (motion h); the lap plate rotates about the centre M of inner and outer gears (motion s). Each crystal passes successively through the positions A-F. Moreover, each blank in the pentagonal holes in the work holders can execute a spinning motion around its own centre by tipping with successive edges against successive sides of the pentagon. This tipping motion comes about in the following way: If only the centrifugal force of the motion h acted on the crystal it would always remain with side I against side 1 of the pentagon. However, the frictional force k_{hs} is also exerted on the crystal by the lap plates and this is opposite in direction to the resultant absolute velocity of the crystal (composed of the velocities v_h and v_s); this force is so much larger than the centrifugal force that the latter in this case may be neglected. Passing through the positions A-F by the crystal amounts to a rotation of the direction of v_s with simultaneous variation of its magnitude between v_{s1} and v_{s2}, while v_h does not change in magnitude or direction (with respect to the pentagon). In fig. b the resulting force k_{hs} on the crystal is shown for a number of positions for a whole revolution of the work holder. As soon as this resultant force in rotating passes a corner of the crystal, the crystal is tipped against the following side of the pentagon.

thinner than in the centre, and the difference primarily will even be greater than desired! Thus, the real problem is to restrict the lapping of edges and corners. This is done by a very simple device: the ring-shaped lap surface of the two iron lap plates is made slightly narrower than the ring covered by the blanks in their cycloid motion. Thus at the inner and outer edges the crystals slightly override the periphery of the lap plates and it should be noted that, due to the spinning motion of the crystals, at successive times that the crystal arrives at the periphery different corners of it will override the latter. On an average the lapping action at the edges and especially at the corners is thereby slightly decreased, equally for all four corners, and by a suitable choice of the amount of override the crystals can be given with good approximation the contour which is desired for a good activity.

The lap plates and the work holders

The two lap plates are made of normalized meehanite. Experiments have also been carried out with lap plates of hardened tool steel, but the advantage of the greater hardness of the steel which should permit a higher lap speed is cancelled by the fact that it resists the embedding of abrasive particles; the latter process ("charging" of the plates) readily occurs with the meehanite and greatly enhances its lapping action. Moreover, steel has the drawback that it is not so easy to make the necessary serrations in it. (The photograph on page 177 in this issue shows how this is done in the case of the meehanite plates.) Smooth steel plates do not lap faster than the meehanite plates with serrations. Glass lap plates give a satisfactory speed of lapping but have the disadvantage of quickly getting out of flat by the abrasive action and that the blank and also the work holders tend to stick to the upper lap plate when it is lifted off.

The pressure on the blanks required for lapping is obtained by giving the upper lap plate a suitable weight. This is not critical. According to the thickness of the blank and the abrasive used weights between 15 and 28 lbs are chosen, so that the average weight per crystal is about 1/2 to 1 lb.

For a uniform distribution of the pressure it is important that the lap plate should rest freely on the blanks, i.e. that the arm which prevents the plate from rotating should not transmit to it any unsymmetrical vertically directed forces. Fig. 5 shows how this is accomplished.

The two lap plates, ground flat with a large surface grinder, are lapped-in by placing them in the machine and allowing the machine to work for a time with the work holders replaced by three massive meehanite gears. The same abrasive is used as will later be used for lapping the quartz. The coarse scratches on the lap plates caused by the previous working with a coarse-grained grinding disc are thus replaced by myriads of nearly invisible grinding scratches which correspond to the grain size of the fine abrasive. The quality of the surface of the lap plates then no longer changes from one lap of quartz crystals to the next. Moreover, during the lapping-in the meehanite plates already get "charged" to some extent (see above).

The work holders are made of linen-base "Bakelite" or "Philite", or of zinc. The first material has the

disadvantage that it tends to become warped, but compared with zinc it is less apt to lead to chipping of the edges of the blanks as they are tipped in the pentagonal holes, it causes less wear on the teeth of the outer and inner gears and it causes less damage when a crack-up occurs while the machine is running. The holders must be at least 0.05 mm thinner than the final lapped thickness of the quartz plates. The five work holders used at one time may not differ from each other in thickness by more than several hundredths of a mm. Well finished work holders can be used several times before they are worn out.

The material of the work holders is much softer than iron, but their teeth are continually "lubricated" with the splashings of the suspension of abrasive so that the already noted wear of inner and outer gears — especially the inner — is quite noticeable: at the level on the gears where the teeth of the work holders lock, the gears are slotted on one side of the teeth. After a number of laps the lower lap plate must be lowered slightly between inner and outer gears so that the teeth of the work holders lock into the gears at a slightly lower level. This operation is made easy by the fact that the lower side of the bottom lap plate has three feet resting on three holders and in addition to these three feet three series of 14 successively shorter feet in a step-like arrangement around the periphery, so that when the plate is lifted and slightly rotated it falls into a slightly lower position. There are thus 15 positions which can be used successively. Then the inner and outer gears can be turned upside down in order to bring into play the other side of their teeth, which has not yet been worn; again all 15 positions can then be used. Only then is it necessary to replace the inner and outer gears by new ones.

Control of the stopping point of a lap

Since lapping with the planetary lap machine proceeds quite rapidly (one lap takes only a few minutes) and since the tolerances in thickness of the quartz plates are so small, it is very important that the lap be stopped at the right moment. The rate of lapping depends upon very many factors, and experience has shown that it is impossible to take these factors into account in such a way that it would be possible to determine the required lap time in advance with sufficient accuracy to meet the close tolerances. It would, therefore, seem obvious to use the same method as that used in the lapping of separate crystals by hand: stop the lapping as soon as it may be assumed that the correct frequency has practically been reached, determine the resonance frequency of one (or more) of the crystals in an oscillator, lap cautiously further according to the difference between the frequency measured and the required frequency. This process can then be repeated several times until one has approached sufficiently close to the desired frequency. In machine lapping however this method is not practical. The measuring of the resonance frequency of a crystal does not by itself offer difficulties — it takes only a few minutes — but the opening of the machine and removing of a crystal is troublesome, time-consuming and always adds the additional risk of a crack-up. It soon develops that a disproportionate amount of time and work is spent on control, as compared with the actual lapping.

An elegant solution of the problem has become possible due to the surprising observation that the resonance frequency of the crystals can be measured *while the machine is running*. During the lapping the crystals receive tiny mechanical shocks from the grains of the abrasive. These shocks cause the AT and the BT plates to vibrate each time, and this they do in the "right" mode with the corresponding characteristic frequency. The result of this vibration is the occurrence of opposite electric charges on the upper and lower surfaces of the quartz plate (normal piezoelectric effect), which change signs in the rhythm of the mechanical vibration. Hence a weak alternating voltage occurs on the two lap plates (which with the crystals between them act as a condenser) and this voltage has a frequency equal to the resonance frequency of the quartz plates (or rather: equal to a kind of *average* resonance frequency; this point will be reconsidered below). If care is taken that the two lap plates are not short-circuited somewhere outside the crystals, the alternating voltage can be picked up with a sensitive standard short-wave receiver and its frequency measured. The latter is done by calibrating the tuning dial of the receiver (at the frequency the lap is to be stopped) with a calibrated variable oscillator which itself may be calibrated with a standard quartz crystal.

During the lapping the operator continually moves the tuning knob back and forth slightly in order to keep the signal that he hears in head phones at maximum intensity. The position of the tuning knob is thus shifted gradually toward higher frequencies as the plates are lapped thinner. When the tuning has reached the previously indicated calibrated piont, the operator stops the machine with a pedal switch. (In principle it is possible to make the control and stopping *automatic*.)

Fig. 7 shows the set-up for this method. In fig. 5 the necessary electrical connections to the lap machine may be seen. The connections must be in shielded cable in order to minimize electrical interference, because the signal of the crystals has an

intensity of only a few microvolts and could thus easily be drowned out by interference or (with inefficient coupling) by noise.

For the purposes of this method work holders of "Bakelite" ("Philite") will be preferred above those of zinc. Although the work holders do not make contact with the upper lap plate, the zinc holders cause a considerable increase in the capacitance between the plates and thus a smaller signal-to-noise ratio.

Fig. 7. Set-up of a planetary lap machine with apparatus for controlling the stopping point of the lap.

The frequency spread

When at the end of one lap the resonance frequency of all 30 crystals in the 5 work holders is measured, precisely the same frequency is by no means found for all of them. The frequencies are found to be statistically distributed about a certain mean value. In view of the fact already mentioned that it is preferable to be able to use all the crystals of one lap for the same communication channel, the frequency spread was a serious obstacle at the beginning of mass production. In order to explain the remedy which was found later we must consider the lap process somewhat more closely.

The surface of a quartz plate becomes smoother the finer the grain of the abrasive used. It has been found that one may be sure of the smoothness required for good activity when one laps with Al_2O_3 303 i.e. a powder of Al_2O_3 (optical flour) with a grain size of about 15 microns. However, the speed of lapping with such a powder is very low, especially when most of the coarse inequalities of previous sawing or grinding operations have been removed. Impossibly long lap times would thus be required.

The method generally followed therefore is that a lot of, for instance, thirty crystals is lapped in at least two and preferably three lapping stages. A coarse powder is used at first, which removes the deep sawing marks present on both surfaces of the crystal plate and thus the largest part of the thickness which must be taken away. The process is repeated with a slightly finer powder which quickly removes the finer scratches and inequalities

left by the first powder, and hence does not need to remove much of the thickness. And one finishes with the finest powder mentioned which laps off the inequalities of the second powder and gives the plate the desired smoothness.

According to our experience the following is a very efficient program:

1) Lapping with SiC 320, i.e. silicon carbide with a grain size of 31.5 μ, to the final thickness $+$ 0.27 mm. This will take about 4 minutes.

2) Lapping off about 0.2 mm with SiC 600 (grain size 17.5 μ), in about 6 minutes.

3) Lapping for about 12 minutes with Al_2O_3 303, thus removing about 0.07 mm.

Assuming a thickness of 0.1 to 0.2 mm to be removed from both sides of a blank in the first lapping stage, one arrives at a total thickness to be lapped off of 0.4 to 0.7 mm, as was mentioned in the introduction.

It is necessary to perform the three laps on different machines in order to eliminate any risk of contamination of the finest abrasive by traces of those previously used. In order that the machine used for the first lap should not stand idle for long times, a group of 5 or 6 machines should be used: one for stage (1), one or two for stage (2), and three for stage (3). The first machine is run with a relatively heavy upper lap plate and at a fairly high speed (outer ring gear 120-150 r.p. min.). The last three machines have the lightest upper lap plate and the lowest speed (35-60 r.p. min.).

With such a set of machines and with this method, operating 20 hours a day, 5000 to 6000 lapped quartz plates can be produced per day.

By this method, under certain circumstances, at the end of the third lapping stage of a lot of crystals a frequency spread of 60 to 125 kc/s was found among the crystals (difference between the highest and the lowest resonance frequencies occurring); in a few cases it was even 200 kc/s. This is much larger than is permissible for good production control. Only where the spread remains below the above-mentioned limit of about 15 kc/s can all the crystals of one lap be subjected together to the final treatment (see below) and need not be further sorted for different communication channels.

It is easy to understand that the spread in thickness of crystals present after the first and second lapping stages is not very objectionable. In making up the first lap one naturally chooses crystals which do not differ very much in thickness (for instance not more than 0.1 mm, which can easily be checked with a micrometer), and then because of the symmetry of the set-up the spread in thickness upon lapping cannot rise above a certain limit [5]). For an investigation of the occurrence and the nature of the spread it is therefore sufficient to consider the situation before, during and after the l a s t lapping stage.

This has been done in an investigation in Dobbs Ferry, in which more than 10,000 quartz plates were measured repeatedly during lapping, and in which various lapping procedures were employed. The most important result was the discovery that the spread is small, namely about 10 to 20 kc/s at 8 Mc/s for the plates of one work holder, and that the large spread often occurring in one lap can be ascribed to d i f f e r e n c e s b e t w e e n t h e w o r k h o l d e r s.

This discovery led to a method to diminish the spread, a method simple enough to be introduced into the factory. The third lapping stage is interrupted at a certain moment, shortly before the end of the expected lap time, all the crystals are taken out of the machine, turned upside down and then distributed in a different way over the five holders so that every work holder now contains plates of the most divergent frequencies ("transposition"). When the lapping is continued the large differences are very quickly equalized since the thickest plates in each holder are by far the most strongly lapped. The lapping may now, however, not be continued too long, since otherwise a greater spread again may develop between the holders! The moment of transposition must therefore be carefully chosen and adapted to all the circumstances of the lapping process. We found a transposition at an average thickness of the plates of 0.015 $\pm$ 0.005 mm above the desired final value to be the most suitable. If the transposition is performed somewhat later the spread within each holder will not be sufficiently closed before the prescribed final thickness has been reached.

In *fig. 8* the frequency of a lap of crystals is given at different moments for a typical case. The effect of the transposition can easily be seen. Thanks to this method one may be assured that not more than about 3-5% of the quartz plates of a lap will fall outside the permissible frequency region, 15 kc/s wide.

The frequency spread naturally leads to the fact that in the above described method of controlling the stopping point of the lap one obtains signals which cover a whole band of frequencies.

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[5]) In fact the spread remains within the errors of actual thickness measurements feasible in a manufacturing process. Thus it would be useless to attempt by actual thickness measurements to match a group of crystals for the next lapping stages closer than the lapping process itself produces. Frequency measurements would render this possible, but they consume too much time for such grouping procedures; moreover, most of the blanks do not yet oscillate in the early lapping stages (cf. below, in connection with fig. 8).

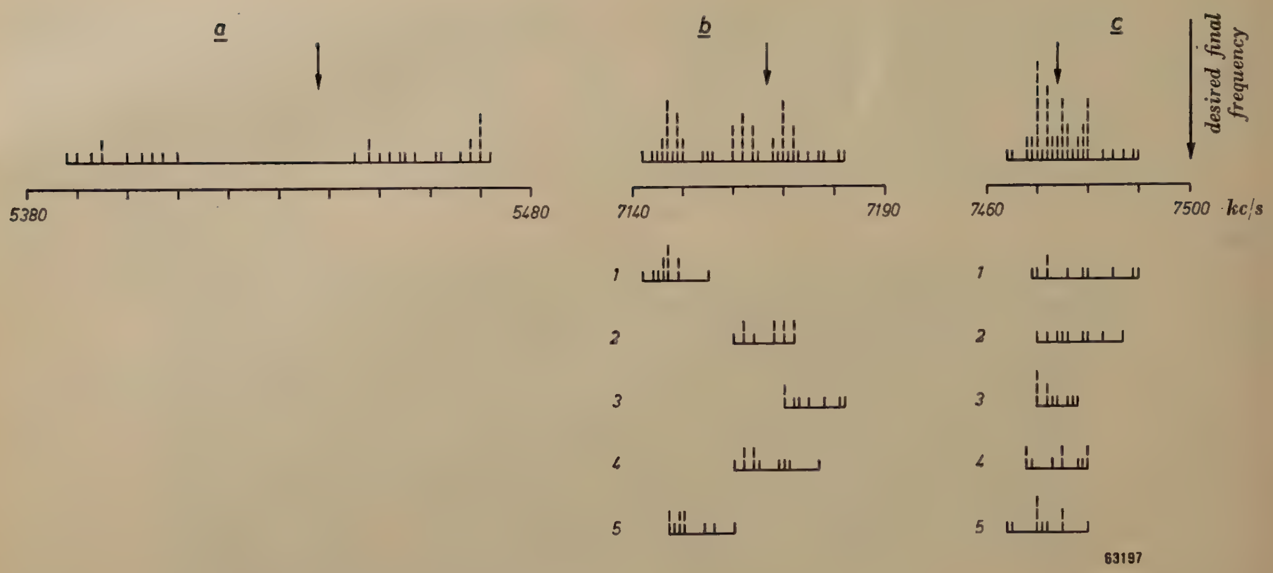


Fig. 8. The frequency spread of a lap,
a) at the end of the second lap stage;
b) after the greater part of the third stage, namely at the moment of transposition; each of the five work holders shows a relatively small spread, but their mutual spread is large;
c) after transposition and conclusion of the third stage.
Each stroke in the vertical line represents one quartz crystal. At the end of the second stage not all the crystals have sufficient activity for oscillating. Only the oscillating crystals can be measured; this will explain why there are more crystals indicated in *b* and *c* than in *a*. The fact is that after the third stage the lap often will contain less crystals than after the first and second stage, as during the lapping some crystals may be broken. These places are not filled by other crystals, for the reason pointed out in note [5]).

The intensity of the signal, however, is found to exhibit a sufficiently sharp peak at the nominal frequency to make the method applicable. The frequency distribution of the signal can be recorded with a recording meter and a good idea of the spread can thus be obtained. *Fig. 9* gives an example of such a recorded distribution curve. The frequencies of the individual crystals of the lap measured immediately after the recording are plotted under the curve.

Final frequency adjustment by etching

The quartz crystals lapped with the planetary lap machine have resonance frequencies which still lie about 10 to 25 kc/s below the desired value. The final adjustment to the desired value within the tolerance of 500 c/s (or closer depending upon the requirements) takes place separately for each crystal. In the beginning the final adjustment was performed carefully by further hand lapping (supplemented if necessary by a small single crystal lap machine). It was found, however, that after some time the crystals thus finished, which had passed all the tests, whether they were used or only kept in store, no longer met the specifications. Their resonance frequency was higher and their activity lower. The situation caused by this unexpected ageing phenomenon at a certain time in 1943 appeared to be catastrophic: millions of oscillator-plates stored in the army magazines of the U.S.A. were found to have become unusable!

An elaborate investigation [6]) led to the conclusion that the ageing was probably caused by a gradual spalling off or recrystallization of the outer layer of the quartz plate. This layer upon lapping with even the finest abrasive is subjected to a treatment which when observed on a submicroscopic scale can be called very rough; after this treatment the layer contains numerous submicroscopic crevices, hills, overhangs etc. In the course of time, and especially through the agency of adsorbed moisture, the projections weather and the effective thickness of the plate decreases, only fractions of a micron to be sure, but this already causes a considerable rise in the resonance frequency. At the same time the loose dust-like deposit of quartz particles remains on the surface and causes a certain damping which has an unfavorable effect on the activity.

The phenomenon can be rendered harmless, as was later found, by removing prior to the testing of the crystals the layer of quartz which is subject to deterioration. This is done by etching in solutions of ammonium bifluoride of a certain concentration and temperature. The effect of etching can be

[6]) Cl. Frondel, Final frequency adjustment of quartz oscillator-plates, American Mineralogist **30**, 416-431, 1945.

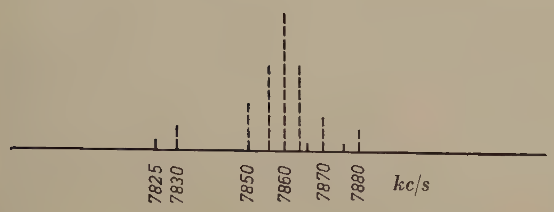


Fig. 9. *a*) Graphic recording of the intensity of the signal produced by 30 quartz crystals in a planetary lap machine as a function of the tuning frequency of the receiver.
b) Individual resonance frequencies of the quartz crystals of (*a*), measured immediately after recording the graph and stopping the machine. Each stroke represents one quartz crystal.

demonstrated by a simple experiment. 50 kc/s are lapped off from a series of crystals with a rather coarse abrasive (e.g. SiC 320) so that a severely damaged surface layer is obtained. A thickness varying between 0 and 10 kc/s is then etched off. The ageing when it occurs takes place rather quickly on the damaged surface. In *fig. 10* the observed ageing is represented graphically: the unetched plates increase by 1.5 kc/s in five days, the plates from which 10 kc/s had been etched off, after a very slight increase in frequency in the first three to four hours, showed no further ageing.

It is now prescribed in all quartz oscillator specifications in the U.S.A. that finished AT and BT plates should have a final layer of at least 1 μ thickness etched off[7]). Thanks to the limited frequency spread it is possible to subject all the crystals of one lap of the planetary lap machine to the greater part of this etching process together. In doing this, the process of course must be controlled with a view to those plates which have the smallest deviation from the final frequency. The final adjustment is by individual etching of each plate under continuous control of the resonance frequency.

[7]) In the case of BT plates for 9 Mc/s this means, as may be derived from the formulae given with fig. 1, that the frequency rises by more than 32 kc/s. In the case of a lap of quartz plates for a nominal frequency in the neighbourhood of 9 Mc/s, therefore, the end of the last stage with the planetary lap machine, expressed in kc/s, must lie considerably farther below the final frequency than in the example previously mentioned.

In this connection it should be pointed out that in lapping and etching, which amount to the removal of material, the resonance frequency is always increased, so that the desired frequency can only be approached from one direction. The possibility also exists of lowering the frequency of a given quartz plate, namely by exposing it to an intense X-radiation. Attempts have been made to put this remarkable phenomenon to practical use (see the article cited in footnote [6])). It was found, however, that the lowering of frequency produced, together with an accompanying darkening of the quartz, disappeared again after some time and particularly at elevated temperatures. This was unfortunate because the method had great advantages; not only could crystals be salvaged which had exceeded their nominal frequency up to 0.02% due to overfinishing, but the crystals could also be irradiated while they were in operation in a valve oscillator and thus it was possible to follow the approach to the desired frequency continuously on a measuring instrument.

However, the same possibilities are now obtained in a different way. Most oscillator-plates made to-day have plated electrodes. The plating, which is put on the crystal either by evaporation in a bell jar or by chemical deposition from a solution, adds to the mass of the vibrating crystal and thereby contributes in determining its resonance frequency. It is thus possible to adjust the frequency a little either down or up by depositing or removing some of the plating without touching the quartz plate itself; and in the evaporation method, similar to the irradiation procedure, it is also feasible to approach the desired frequency under continuous control as described above.

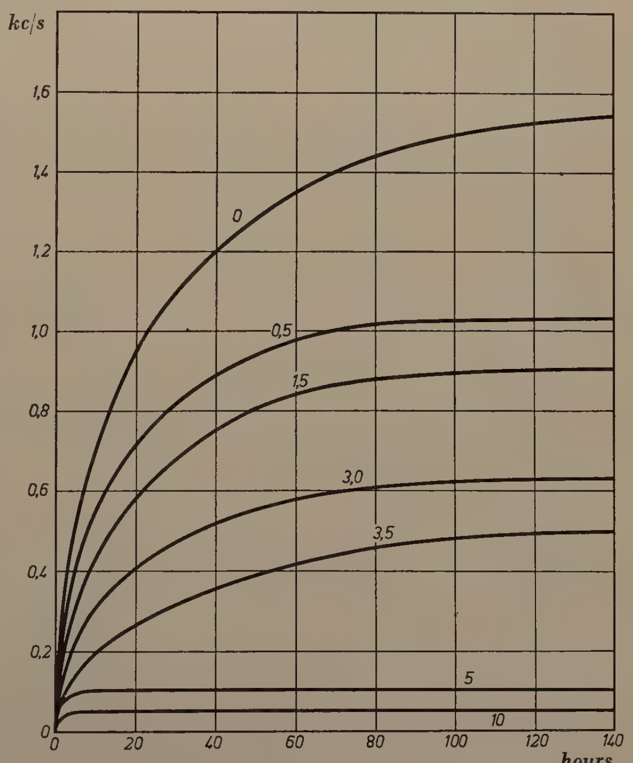


Fig. 10. Ageing observed in BT quartz crystals for about 8 Mc/s, from which 50 kc/s has been lapped off with a coarse abrasive (SiC 320) and then a layer varying from 0 to 10 kc/s etched off. The resonance frequency measured is plotted as a function of the number of hours elapsed since the etching. (From C. Frondel, Amer. Mineralogist **30**, p. 422, 1945.)

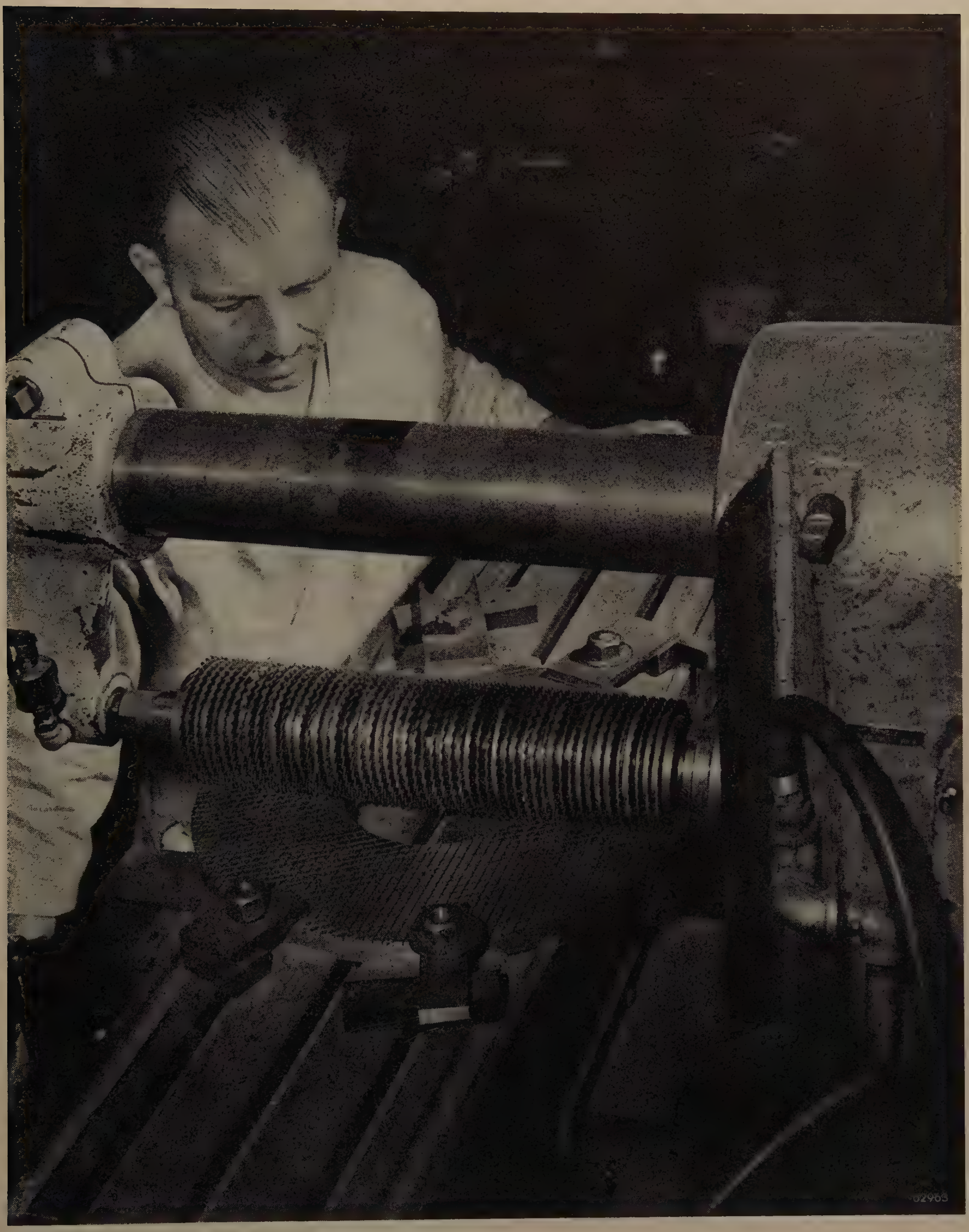
Plates finished by etching are also not perfectly stable as to the frequency. Where extreme requirements are made as to stability, thus where every trace of ageing must be avoided, the best results are apparently obtained, according to recent investigations, by heating the quartz plate to 500 °C, i.e. just below the transition point from α to β quartz, and then cooling it slowly [8]).

This concludes the survey given in three articles of the development of the manufacture of quartz oscillator-plates in the war years. In general the methods followed by the quartz producers still working are similar to those here described. The number of plates produced is of course very much smaller. However, the fact that such efficient methods of manufacture are available cannot help but have a stimulating effect on the use of quartz plates, so that the applications in peace time of these plates increase continually in importance.

[8]) A. C. Prichard, M. A. A. Druesne and D. G. Mc Caa, Acta Cryst. **3**, 73, 1950 (No. 1).

Summary. The AT and BT blanks 1.0 to 1.2 mm in thickness sawed from a quartz crystal are lapped off in three stages with successively finer abrasive to a thickness of 0.3 to 0.8 mm, according to the desired resonance frequency. This operation can be performed mechanically with the planetary lap machine with which 30 to 55 plates are lapped simultaneously. At the same time the plates automatically take on the contour necessary for good "activity". With six of these machines three lots of crystals can be finished in less than 15 minutes of actual running time. The moment at which the plates have reached the desired thickness is determined by measuring the resonance frequency of the crystal while the machine is running; this is possible because of the fact that the crystals are continually brought into vibration by the lapping process, the piezoelectric effect thereby causing a weak alternating voltage on the lap plates. By a transposition of the crystals of a lap at a certain moment in the third lap stage the frequency spread of the lapped plates is kept within about 15 kc/s (at 8 Mc/sec). After lapping, at least 1 micron is etched off from the crystals in a water solution of ammonium bifluoride. Each crystal is then adjusted accurately to the nominal frequency by further individual etching. Crystals finished in this way are practically free of ageing phenomena.

MAKING LAP PLATES
FOR THE MANUFACTURE OF QUARTZ OSCILLATOR-PLATES



Crossed serrations, in which the abrasive can accumulate, being milled into the meehanite plates of the planetary lap machine used for the mass manufacture of quartz oscillator-plates (see the article on that subject in this number).

MEASURING THE DEIONISATION TIME OF GAS-FILLED DIODES AND TRIODES

by K. W. HESS.

621.314.67:621.385.38:537.567.569

The charge of the ions compensating the space charge formed by the electrons in a gas-filled discharge tube is neutralized mainly on the walls and the electrodes of the tube. After the current has ceased to flow it takes a certain time for the tube to become free of ions again. If the tube is to be used periodically this finite deionisation time sets a limit to the permissible frequency.

Introduction

In a vacuum tube, if the anode voltage is not abnormally high, the current is determined mainly by the space charge of the electrons. In gas-filled tubes this space charge is neutralized by the positive gas ions, so that at low voltages it is possible to send heavy currents through these tubes. In this article we shall devote our attention particularly to the influence that ions have on the properties of gas-filled diodes and triodes (also called relay valves or thyratrons); we shall not deal with the phenomena occurring, for instance, in "TL" lamps, neon tubes, etc.

So long as the voltages between the electrodes are not high enough to bring about a gas discharge the passage of current through a gas-filled tube is comparable to that in a vacuum tube, but as soon as the anode voltage exceeds a certain value, the ignition voltage, the tube begins to function as a gas tube. In a diode this ignition voltage has an almost constant value, whilst in a triode it is greatly dependent upon the grid voltage. This means that in the case of a triode for every value of the anode voltage (provided it is not too low) there is a certain critical grid voltage above which the tube ignites. Contrary to the case of a vacuum triode (except for some rare cases), after the ignition has taken place the grid voltage has practically no influence upon the current passing through the tube. The reason for this is that when the grid is negative a space charge of positive ions is built up around it and neutralizes the negative potential.

After the current has ceased to flow not all the gas ions will immediately recombine. In general the rule is that the number of ions σ in the tube decreases with the time t according to an exponential function:

$$\sigma = \sigma_0 \, e^{-\frac{t}{\tau_0}}.$$

The characteristic time τ_0 in this formula may be called the deionisation time. It depends, of course, upon the possibilities present for the ions to lose their charge. This takes place mainly on the walls and electrodes of the tube, and it will therefore be greatly affected by the manner on which the tube is constructed. The less positive, or, as often occurs, the more negative the voltage at one or more of the electrodes, the shorter is the deionisation time, whilst on the other hand the greater the preceding anode current the longer is the deionisation time. Finally τ_0 increases with increasing gas pressure [1]).

What is of importance in practice is not the deionisation time as defined above but rather the effective deionisation time, τ_{eff}, which is the period of time that has to elapse, after the current has ceased to flow, until the working of the tube is no longer affected by the remaining ions. Obviously, τ_{eff} will have a different value for each different application of the tube [2]). The deionisation time will be particularly noticeable when the tube is working periodically, as for instance in a rectifying circuit or in a relay circuit, when at every ignition ions may still be present in the tube owing to the preceding flow of current through it.

Let us first consider the case of a diode. As already indicated, the tube ignites when the anode voltage reaches a certain value. In many cases this ignition voltage depends upon the number of ions in the tube, being lower the more ions there are. When for a particular application the ignition voltage is required to be above a certain value then it

[1]) For this subject see, e.g., H. B. de Knight, Proc. Inst. Electr. Engrs **96**, Part III, 257, 1949.

[2]) In literature all sorts of definitions are given for the deionisation time, but mostly it is the effective deionisation time that is meant, in some form or other. The essence of the conception of deionisation time is certainly implied in our original definition.

is necessary to ensure that the interval of time between two successive ignitions is so large that the ignition voltage for the second ignition, lowered by the presence of ions due to the first passage of current, does not fall below that prescribed level. In other words, there is an effective deionisation time setting an upper limit to the frequency at which the tube can be worked.

A similar effect arises in the case of a triode. The space-charge sheath formed around the grid while current is passing does not immediately disappear after the current ceases to flow. Consequently the tube cannot be controlled by means of the grid potential until a certain effective deionisation time has elapsed. When a sufficiently high anode voltage is applied before that time has expired the tube will reignite while the grid voltage is still below the critical voltage corresponding to that anode voltage. Thus there is again an upper limit set for the frequency at which the ignition of the tube can be controlled with the aid of its grid voltage.

For all kinds of rectifying tubes, both diodes and triodes, the finite deionisation time in fact increases the risk of backfire in the tube: when the anode voltage is strongly negative while there are still many ions in the tube it is quite easy for a glow (sometimes arc) discharge to take place, causing electrons to travel from the anode to the cathode. For this effect, too, an effective deionisation time can be defined, which is generally much shorter than the deionisation times referred to above. However, we shall not consider this phenomenon any further here.

In this article we shall discuss some methods for measuring the deionisation time in various cases taken from practice. We could carry out the measurements with a variable frequency and determine at what frequency the tube ceases to function properly, but this is impracticable on account of the usually high power consumption and the technical difficulty of arranging a measuring set-up for any desired frequency. We prefer to use a system producing a condition which, when working at the mains frequency, is comparable to the working of the tube with the desired frequency, then determining τ with the aid of an oscillograph.

Measurement of the deionisation time in a triode by means of the grid current

First we shall describe a method for determining easily and quickly the order of magnitude of the deionisation time in a triode, using for that purpose a direct indicator of the number of positive ions in the tube, namely the grid current. An alternating voltage is applied to the anode circuit of the triode to be tested, while the grid is connected via a resistor to a negative voltage source. The negative voltage is chosen high enough to ensure that the tube cannot of itself ignite during the positive half-cycle of the alternating voltage on the anode circuit. At a moment t_1 during this half-cycle the grid receives a voltage impulse from a peak transformer such as described, for instance, in an article recently published in this journal [3]), the value of this impulse being so chosen as to cause the tube to ignite. Current then begins to flow and the anode voltage drops to the level of

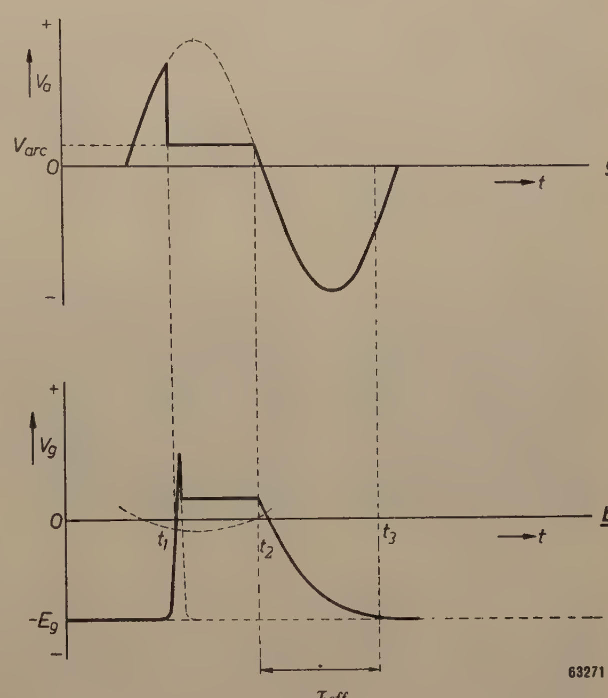


Fig. 1. The variation of: *a*) the anode voltage, *b*) the grid voltage of a gas triode fed with alternating current. At the moment t_1 the grid, which normally has a negative bias $-E_g$, receives a voltage impulse causing the tube to ignite. The anode voltage then drops to the arc voltage level V_{arc}. At the moment t_2 the tube is extinguished on account of the anode voltage dropping below V_{arc}. During the working period the grid voltage is kept at a certain level as a consequence of the positive ion current (this level being generally somewhat lower than the arc voltage). After extinction of the discharge the ions gradually disappear and the grid voltage gradually drops to the level $-E_g$, which is reached at the moment t_3. Thus the interval of time t_3—t_2 is a measure of the deionisation time.

the arc voltage V_{arc} (*fig. 1a*). When at the moment t_2 the alternating voltage drops below the arc voltage the tube extinguishes. The grid voltage, which after the very short impulse would tend to

[3]) K. W. Hess and F. H. de Jong, Controlling the luminous intensity of fluorescent lamps with the aid of relay valves, Philips Techn. Rev. 12, 83-93, 1950 (No. 3).

drop again to the original negative value, is kept at a level usually positive and somewhat lower than the arc voltage, owing to the voltage drop in the grid resistor brought about by the ion current flowing to the grid. Thus the voltage at the grid is a measure of the ion current. After the extinction of the tube ions continue to be present in it for some time, though diminishing in number, and the grid voltage gradually drops to its original negative value (fig. 1*b*), which is reached at the moment t_3. Thus t_3—t_2 is a measure of the deionisation time.

By keeping the frequency of the A.C. anode voltage low (the mains frequency of 50 c/s is highly suitable) the moment t_3 can be made to fall within the negative half-cycle of that voltage. The whole phenomenon is repeated in the next cycle of that voltage, the tube striking at the moment t_1' when the grid receives the next voltage impulse. By displaying the grid voltage on the screen of an oscillograph it is quite easy to determine the order of magnitude of the deionisation time. Some oscillograms obtained in this way have been reproduced in *fig. 2*.

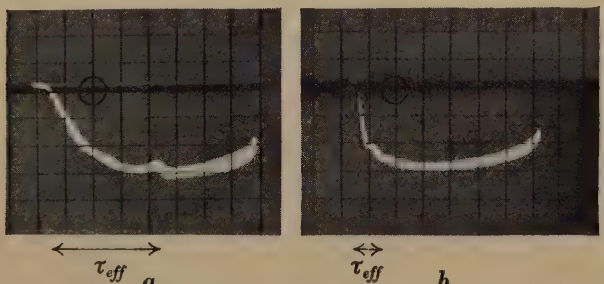


Fig. 2. Two oscillograms showing the variation of the grid voltage, *a*) for a tube with long deionisation time (about 4 msec), and *b*) for a tube with short deionisation time (about 1 msec). The part of the curve denoting the variation of the grid voltage prior to the moment t_2 (cf. fig. 1) is not included in these oscillograms.

To determine accurately the effective deionisation time for a specific case occurring in practice we must follow other methods, some of which will be described below.

Measurement of the effective deionisation time

Deionisation in a triode

We shall now deal with the measurement of the effective deionisation time which in the case of a triode determines what period of time has to elapse after the current ceases to flow before the grid is again able to prevent ignition. Here we use the set-up illustrated diagrammatically in *fig. 3*.

The heavily lined current circuit ("low-voltage circuit") serves for the production of the ions and the heating of the tube G under test to its working temperature; the transformer T_2 supplies a voltage (between 30 and 60 V) just high enough to send the desired current through the circuit formed by

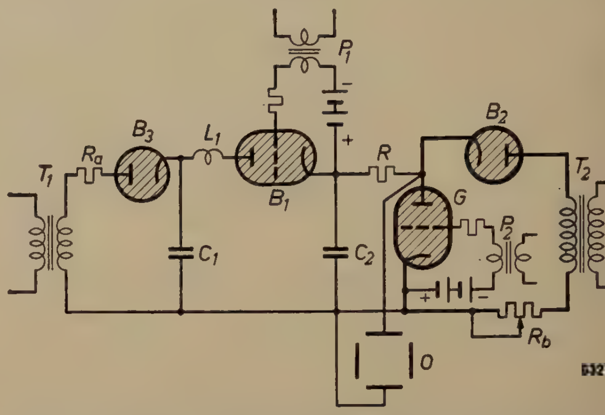


Fig. 3. System for measuring the effective deionisation time of a triode. The manner in which it functions is described in the text. The right-hand part of the diagram T_2-B_2-G-R_b supplies G, the tubeu nder test, with its correct anode current, thus maintaining it at its operating temperature. The left-hand part of the diagram shows the system foı producing positive voltage pulses with steeply ascending front. The voltage across G is displayed on the screen of an oscillograph.

T_2, B_2, G and R_b. The function of the gas-filled diode B_2 will be made clear presently; R_b is a load resistor. The grid of G is connected to a negative-voltage source; connected to the grid circuit is also a peak transformer P_2. At some time duıing the positive half-cycle of the anode voltage of G, say at the moment t_1 (*fig. 4a*), the grid receives a voltage impulse causing G to ignite, and the anode voltage drops to the arc-voltage level (the rest of the voltage is taken up by R_b). At the moment t_2 the anode voltage drops below the arc-voltage level and G extinguishes. During the negative half-cycle the voltage appearing across G is determined by the very low conductance of G in the extinguished state and of the diode B_2 (likewise extinguished). To a first approximation we may say that this voltage is zero. The whole process is repeated during the next cycle.

Now we suppose that at the moment t_3 (during the negative half-cycle of the transformer voltage) the gas-filled triode B_1 is ignited by an impulse reaching its grid from the peak transformer P_1. The charge from the capacitor C_1, forming part of the rectifying circuit T_1-R_a-B_3-C_1 ("high voltage circuit"), is thereby caused to flow through the self-inductance L_1 and through B_1 to C_2, thereby charging C_2; with the right selection of C_1, L_1 and C_2 this charging can be made to take place very quickly. B_1 automatically extinguishes again as soon as the charging of C_2 is ended. The anode of

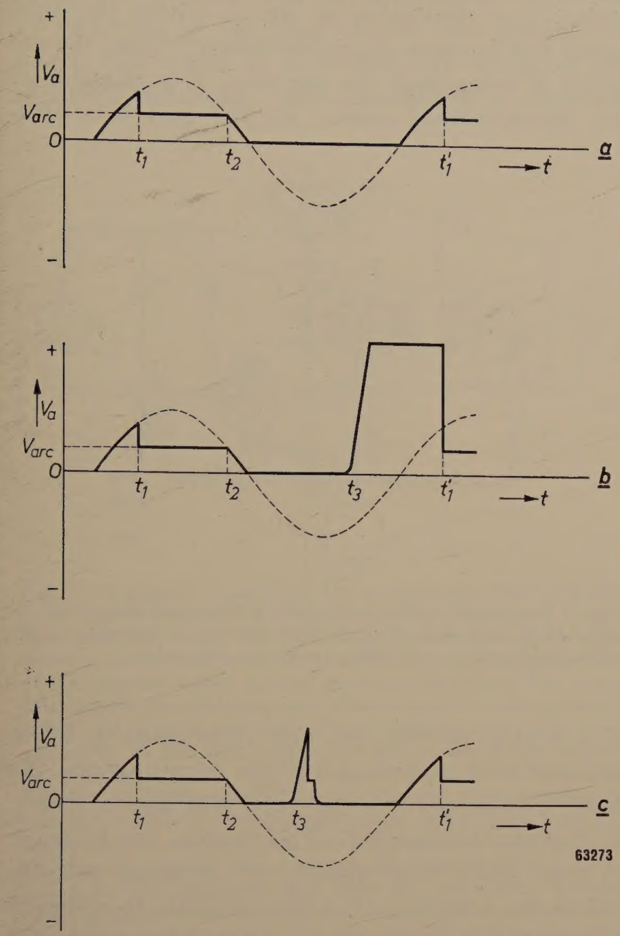


Fig. 4. *a*) Variation of the anode voltage of G in the system of fig. 3 when there is no voltage across the capacitor C_2. At the moment t_1 the tube G is ignited by an impulse on its grid, whilst at the moment t_2 it is extinguished owing to the anode voltage dropping below the arc voltage. The fact that there is no negative voltage across G during the negative half-cycle of the transformer voltage is due to the presence of the diode B_2 (see fig. 3). The process is repeated in the next cycle. *b*) As in (*a*) but during the negative half-cycle the tube B_1 is fired at the moment t_3, as a result of which a positive voltage appears across G; G does not ignite, however, because its grid voltage is negative and there are few ions in the tube, since t_3—t_2 is longer than the effective deionisation time. The voltage does not then drop again to V_{arc} until the moment t_1' when the grid of G receives another impulse and G ignites. *c*) As (*b*) but with t_3—t_2 shorter than the effective deionisation time. The tube G ignites owing to the presence of sufficient ions, in spite of the low grid voltage, as soon as the anode voltage reaches a certain value. This value depends upon the number of ions, and thus upon t_3—t_2. The voltage across G then drops within a few µsec to the arc voltage level and, after completion of the discharge of C_2, to zero.

G thus receives a voltage impulse with a steeply ascending front, as sketched in fig. 4*b*. The amplitude of the voltage supplied by T_1 (some hundreds of volts) and the values of the circuit elements C_1, L_1 and C_2 are so chosen that the height of this pulse is greater than the voltages generally occurring in practice, but not so great that, in the absence of ions in the tube, G will strike at the given negative grid bias. When the aforementioned condition is fulfilled the capacitor C_2 will therefore not be able to start discharging until G ignites owing to excitation of its grid by an impulse, i.e. at the moment t_1'.

If, however, the moment is so chosen that there are still ions in G when C_2 is being charged, then G will ignite, without a grid impulse, when the anode voltage — i.e. the voltage across C_2 — exceeds a certain value. The charge from C_2 will then flow off directly through G. The voltage that has to lie across G to cause the tube to ignite obviously depends on the number of ions in the tube; thus the shorter the interval t_3—t_2 the lower is the peak voltage that appears across C_2 (fig. 4*c*).

Since the phenomenon is repeated at the mains frequency the voltage across G can be displayed on the screen of the oscillograph and we can thus easily determine at what interval of time the full voltage across C_2 can still be borne by G. To do this we have to vary the phase shift between the impulses from P_1 and P_2. This can be done in various ways. In our experiments we used an induction regulator, consisting of an induction motor with fixed rotor and the stator connected to three-phase mains. The primary current for one of the peak transformers is taken from the rotor winding and by turning the rotor by hand it is possible to shift the phase of this current with respect to the stator phase.

The minimum interval of time between the extinction of G and the impulse on C_2 at which the tube G still does not ignite is the effective deionisation time sought. Some oscillograms of the phenomenon are represented in *fig. 5*, which clearly show that as the interval of time is reduced the height of the impulse sufficient to cause G to ignite is also reduced.

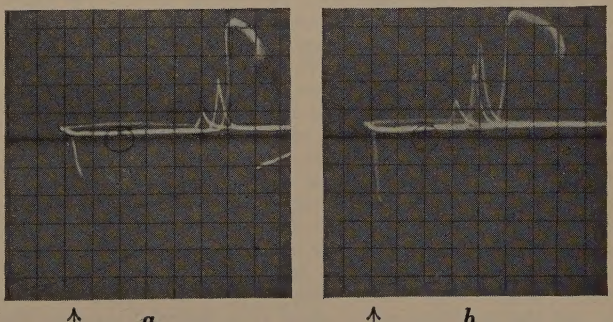


Fig. 5. Two oscillograms of the phenomenon described in fig. 4, *a*) for a tube with long τ_{eff} (1.2 msec), *b*) for a tube with short τ_{eff} (0.85 msec). Only the variation of the anode voltage in the interval of time from t_2 up to shortly after t_3 is represented, the curves for different intervals t_3—t_2 being shown in the same oscillogram. It is clearly seen how the height of the impulse at which G just ignites varies with this interval of time. The descending slope of the impulse is not discontinuous as in fig. 4*c* but gradual, owing to the influence of the measuring potentiometer. The arrow pointing to the small vertical line on the left of the oscillograms indicates the moment t_2.

The purpose of the tube B_2 in the heavily lined part of the system is to prevent the charge from C_2 flowing away through the secondary winding of T_2 when the tube G is not ignited.

Since B_2 prevents the anode of G from becoming negative (with a negative anode the ions, of course, recombine more rapidly), this set-up furnishes a very safe velue for the deionisation time.

As the definition of the effective deionisation time shows, this time varies according to the practical application of the tube. By making a small alteration to the "low-voltage circuit" of the system according to fig. 3, we can adapt this for measuring the effective deionisation time of a triode used in a polyphase rectifying circuit. In such a circuit there are several rectifying tubes (here triodes), with the current passing through each of them in turn. When commutating, the current flowing through a tube very rapidly drops from a fairly high level to zero [4]). In this case a longer effective deionisation time is to be expected than in the case of a single-phase rectifying circuit. The alteration made to the "low-voltage circuit" of fig. 3 is illustrated in *fig. 6* and explained in the subscript.

For tubes not passing too high a current the system of fig. 3 can be simplified, the working current being supplied directly by the "high-voltage

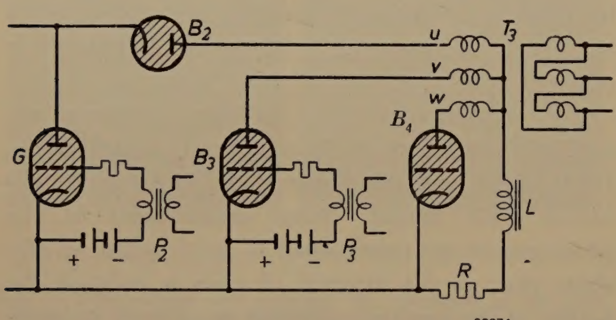


Fig. 6. The "low-voltage part" of the system for the measurement of the effective deionisation time in a triode G contained in a polyphase (here three-phase) rectifying circuit. The tubes G, B_3 and B_4 are connected to the successive phases u, v and w of the three-phase transformer T_3. In the part of the cycle when the anode of G is positive G is ignited by a voltage impulse from the peak transformer P_2 applied to the grid (which is normally so heavily biassed as to prevent G from striking of itself). It is known that in such a circuit two of the tubes cannot conduct simultaneously (see the article quoted in footnote [4])). B_3 is now ignited by an impulse applied to its grid from the peak transformer P_3 at a moment when the voltage of phase u has not yet dropped below the arc voltage of G but the voltage of phase v already exceeds the voltage of phase u. As soon as B_3 is ignited the current through G very quickly drops from a fairly high value to zero, and this is just the condition under which it is desired to measure the effective deionisation time. By varying the moment of ignition of B_3 it is possible to change the conditions under which the effective deionisation time of G is measured.
The tube B_4 (the grid of which is so heavily biassed that the tube normally strikes as soon as the voltage of phase w exceeds a certain value) serves only for ensuring a practically constant value of the current supplied by T_3.
B_2 again prevents the capacitor C_2 (cf fig. 3) from discharging through the transformer.

[4]) Tj. Douma, Voltage impulses in rectifiers, Philips Techn. Rev. 9, 135-146, 1947.

circuit", as illustrated in *fig. 7*, where the tube under test is again represented by G. Upon the gas triode B being fired the capacitor C is charged by the direct-current source A. The grid bias of G

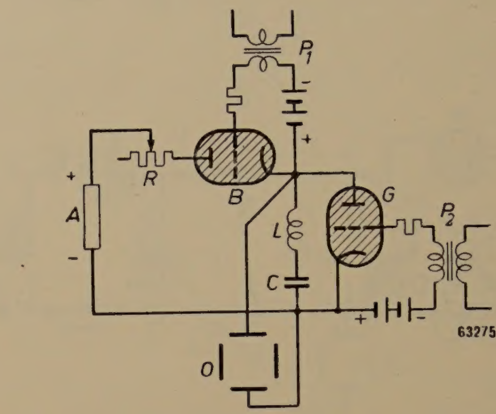


Fig. 7. Simplified system with which the same object can be achieved as with that of fig. 3. Here there is no separate circuit for supplying the operating current for the tube.

is such as to prevent this tube from igniting. When the grid of G receives a voltage impulse from the peak transformer P_2 the tube will ignite and C is discharged through G. This process can be made to take place very quickly by choosing suitable values for L and C. It is then possible to re-ignite B, and C is recharged by applying an impulse to the grid of B.

If the interval of time between the discharge of C through G and its recharging is longer than the effective deionisation time then C will remain charged, but if that interval of time is shorter then C will discharge through G as soon as the voltage reaches a certain value. Thus it is possible to determine the effective deionisation time by measuring with the aid of an oscillograph the voltage across G as a function of the interval of time (variable with a phase regulator) between the impulses on the grids of G and B.

In this case the anode of G is negative during part of the cycle owing to the influence of L.

Deionisation in the case of a diode

We shall now describe an oscillographic method of measuring the effective deionisation time determined by the decrease of the ignition voltage of a diode, taking as example a diode used in a relay circuit. For the proper functioning of such a circuit it is necessary for the ignition voltage of the diode to exceed a certain value. The case chosen is that of a glow-discharge tube with cold cathode, but the method to be described applies equally well for a diode with heated cathode. The circuit is given

in *fig. 8*, where the heavily lined circuit represents an imitation of the relay circuit. The principle on which this works is as follows. By means of two identical networks, each containing a controlled

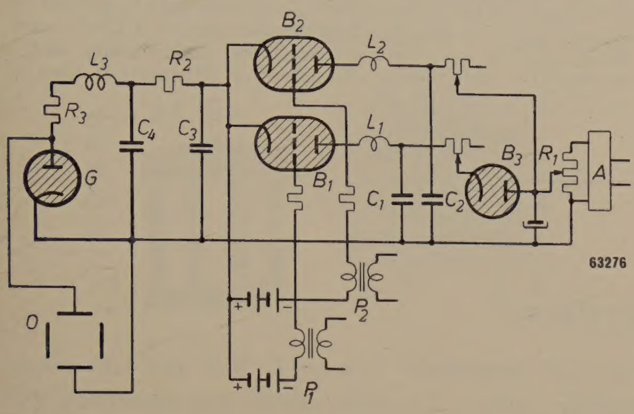


Fig. 8. System for measuring the deionisation time of a diode G in a relay circuit. The choke L_3 and the resistor R_3 form an imitation of a relay. C_3, R_2 and C_4 determine the form of the impulse, which has to resemble as closely as possible the shape of the impulse under normal working conditions. The system functions in the following way. When a positive voltage impulse (from the peak transformer P_1) is applied to the grid of the gas triode B_1 this tube ignites and the charge of the capacitor C_1 is transmitted to C_3 and thence to C_4. When the voltage across C_4 is high enough G ignites, C_4 and C_3 then being discharged, and G is extinguished again. After some time B_2 is ignited by an impulse from the peak transformer P_2. B_2 and B_1 work in exactly the same way (the circuits $B_1L_1C_1C_3$ and $B_2L_2C_2C_3$ are identical) and thus the process is repeated, G being ignited and extinguished again. If as a result of the first ignition there are ions in the tube G at the moment of the second ignition then the ignition voltage will be lower the second time and the peak voltage of the impulse across C_4 will not have the maximum value. By measuring this peak voltage as a function of the interval of time between the two impulses the deionisation time of the tube G is determined. The easiest way to do this is to make the phase of one of the peak transformers (P_2 in the diagram) variable with respect to that of P_1 by means of a phase regulator (see the text) and then to apply the anode voltage of G to the vertical deflection plates of an oscillograph.
The tube B_3 serves to prevent the capacitor C_1 being charged by C_2 when the interval between the impulses is short. The whole system works with a frequency of 50 c/s.

gas triode, positive voltage pulses can be applied to the anode of the tube G under test, with variable interval of time between the two pulses. The first pulse causes the tube to ignite, and after the discharge of the capacitors C_4 and C_3 the voltage across the tube drops below the arc voltage and the tube is extinguished. When the anode receives the next pulse the tube is reignited and the process is repeated. If ions were still present in the tube at the moment of the second pulse then the ignition voltage would be lower than that for the first pulse and the measured peak voltage of the second pulse would be lower than the normal ignition voltage (*fig. 9*). By varying the interval of time between the two pulses we can follow the variation of the peak voltage for the second pulse and thus determine the time which has to elapse between the two pulses for the peak voltage of the second one to be just as high as that of the first. This is the deionisation time. The whole phenomenon can be seen on the screen of the oscillograph. A description of the system employed is given in the subscript to fig. 8.

It must be pointed out that in order to get an exact measurement of the deionisation time it would really be necessary to determine the time elapsing between the moment that the current due to the first pulse ceases to flow through G and the moment that the voltage *begins* to rise as a result of the second pulse, ignoring the "rise time" of that voltage. Now from *fig. 10*, sketching the variation of the current passing through G during an impulse, it is obvious that it would be very difficult to determine exactly at what moment

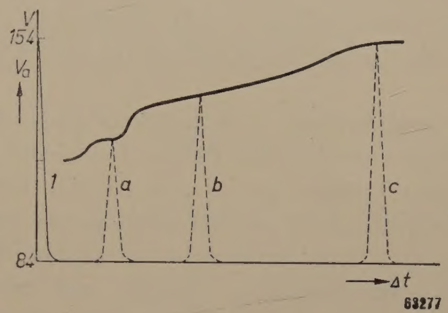


Fig. 9. Variation of the peak voltage of the second impulse at the anode of G (in the system according to fig. 8) as a function of the interval of time Δt between two impulses. When there are no ions present the ignition voltage of the tube is 154 V and the operating voltage is 84 V. Curve *1* is the variation of the anode voltage of G due to the first impulse. The dotted impulses *a*, *b* and *c* indicate how the anode voltage varies during the second impulse. The maximum value of this voltage depends upon the interval of time between the second and the preceding impulse. The heavily drawn curve shows how the ignition voltage at the second impulse varies according to that interval of time.

the current actually ceases to flow, and that is why we prefer to measure the interval of time between the beginning of the first impulse and the beginning

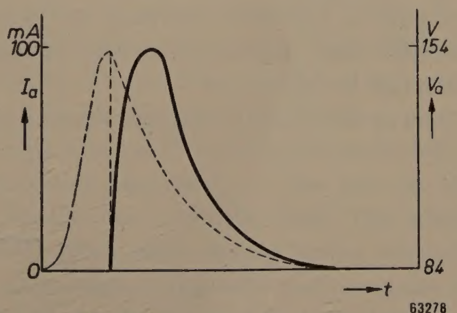


Fig. 10. Variation of the current passing through a glow-discharge tube with cold cathode during a voltage impulse on the anode, plotted as a function of time. The moment at which the current ceases to flow cannot be exactly determined. The variation of the anode voltage is indicated by a dotted line.

of the second one. For all practical purposes this is the most important interval of time; in this way the maximum switching frequency at which the tube can function is determined directly.

Summary. Effective deionisation time is defined as the time required, after current has ceased to flow, for the ions in a gas-filled tube to be so far recombined as no longer to have any adverse effect upon the working of the tube. It is useful to be able to measure this effective deionisation time in cases where a gas-filled tube has to be switched on and off several times per second. The deionisation time determines the maximum frequency for which the tube is suitable. Descriptions are given of: a method for determining quickly the order of magnitude of the deionisation time in a triode, a system for determining the effective deionisation time of a triode used, inter alia, in a polyphase rectifying installation, and a method for determining the effective deionisation time of a diode in a relay circuit.

BOOK REVIEW

Application of the Electronic Valve in Radio Receivers and Amplifiers. Volume 1: R.F. and I.F. amplification - Frequency changing - Determining the tracking curve - Parasitic effects and distortion due to the curvature of valve characteristics - Detection, by B. G. Dammers, J. Haantjes, J. Otte and H. van Suchtelen; 416 pages, 256 illustrations. — Published by N.V. Philips' Gloeilampenfabrieken, Technical and Scientific Literature Department, Eindhoven, Netherlands, 1950.

This book belongs to the series of books on electronic valves published in Philips Technical Library. Two other volumes are in preparation. Volume 2 will deal with A.F. amplification, power amplification, inverse feedback and power supply; volume 3 with control devices, stability and instability of circuits, parasitical feedback, interference phenomena and calculations of receivers and amplifiers. In this book only amplitude-modulated signals are considered. The reader is presumed to be acquainted with the theory of the electronic valve itself and to have some general knowledge on radio receivers. In the more than 400 pages the subjects covered by the title are dealt with in detail, and full calculations of many circuits are given. A list of symbols at the beginning of the book is helpful in understanding an arbitrary section of the book that might be chosen for study. An extensive contents helps the reader to find the topics in which he might be particularly interested. At the end of each part a bibliography is included referring the reader to some of the more important articles on the subjects covered by the part.

The part on R.F. and I.F. amplification starts with a discussion of the single tuned circuit, followed by an extensive treatment of two coupled circuits. Special attention is paid to the various ways of coupling an aerial to a tuned circuit and of attaining a variable bandwidth in the I.F. amplifier. Circuits for image suppression are not included. In the part on frequency changing the properties of oscillator circuits are dealt with extensively. Separate sections are devoted to squegging oscillation and to frequency drift. This is followed by a separate part on the determination of the tracking curve. The next part deals with effects due to the curvature of valve characteristics: cross-modulation, modulation distortion, modulation hum, whistles. In the part on detection most attention is paid to diode detection, which is fully treated. The result of a difference between D.C. and A.C. resistance in the diode circuit and the reaction of the diode circuit on the preceding tuned circuit are clearly elucidated. All parts are written clearly and the reader is given full information on any of the subjects treated in the book.

B. D. H. Tellegen